PRINCIPLES OF PERCEPTION

Second Edition

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To those
who most wish
psychology
to be a science

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Preface

Because *Principles of Perception* first appeared slightly more than a decade ago, it has become advisable to revise it most importantly in order to recognize the vast amount of work completed since then, including the emergence of a literature on the perception of speech.

The original edition of *Principles of Perception* was an attempt to portray the human organism's immediate reactions to environment as dependent upon the energistic activity described by natural scientists—the physicists and chemists. Since psychology was envisaged as a natural science, no other starting point was thought possible. This approach has been retained in the revision but with amplification of the relation of perception to the phenomena that more particularly interest many psychologists.

Another factor in the revision has been a further clarification of the relation between the sets of phenomena called sensations and those called perceptions. The task has been facilitated by the recent appearance of Gibson's *The Senses Considered as Perceptual Systems*. Gibson has provided a new basis for retention of the two terms "sensation" and "perception" in labeling immediate discriminatory reactions; up to this point the need for two terms rather than one had nearly vanished.

Gibson defines sensations as the experiences one has under certain conditions as a result of the mediation of sense mechanisms, and he defines perceptual response as a more active outgoing interaction with the environment that involves the participation of several sense mechanisms. He points out that one does not have to experience sensations in order to make a perceptual response. While Gibson minimizes the relevance of the analytical

study of the sense mechanisms that has preoccupied many investigators over the past century, I have assumed that the role of such analysis is fundamental, and in the present revision I have retained the description of such studies as a foundation for dealing with immediate discriminatory behavior in the more nearly global way of everyday life called perceptual response. Only after the student has become familiar with the mediating machinery of the body and the specific results that accrue from its functions is he prepared to deal with what is called perception. Barring this pre-exposure he will continue to see perception in no way other than the way the man-on-the-street does. He will pick up some of the vocabulary used in the professional description but the words will be empty of the meaning they should contain. The present revision therefore retains the plan of dealing with sense modalities in serial fashion before coming to the discussion of perception as such. I have relegated theories of perception to the final chapter.

The revision may lack material some readers might expect to find in it. The variety and diversity of studies in perception has become so enormous that nothing short of a huge encyclopedia could cover them. I am mindful that *Principles of Perception* is a textbook for less-than-advanced graduate students. I believe that it does not work very well to provide a text so inclusive that the instructor must eliminate considerable material in teaching the course. Any instructor is at liberty to add to what he finds in a textbook, but to eliminate forces him into poorer pedagogy.

I thank the various authors and journals, named throughout the book, for their permission to reproduce their materials.

I thank Dr. Robert B. Freeman of Pennsylvania State University for his extensive and valuable suggestions regarding revision.

I express my gratitude to Mrs. LeAnn Slicer, my secretary, for her part in producing the revision. It would have been totally impossible without her intelligent and devoted participation, made in the face of the usual gaff of daily duties and interruptions. Mrs. Slicer more than compensated for the proverbial absent-mindedness of a professor especially evident under such circumstances.

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Introduction

This is a textbook about perception. It is a compilation of facts about perception but it is also a development of a usable view of perception and a description of the methods whereby it is studied. Not all people have the same idea of what perception is, so one of the first tasks is to indicate what is to be understood as perception in this book.

TWO APPROACHES TO DEALING WITH BEHAVIOR

In general there are two broad ways of dealing with the activities of organisms, including the human organism. One is to observe them, classify them to the extent possible, and give them names. These names do not refer to behavior at some specific time and place or definitively to the conditions under which the behavior occurs. One may call this a longitudinal approach. The other approach is to deal with specific acts of behavior called responses, which relate to the conditions that are assumed to elicit them. As close a connection as possible between the conditions, called stimuli, and the resulting responses is aimed at. In general, this is called stimulus-response psychology and within it are several major concerns among psychologists. For example, some study *learning* and memory, or recall; some study *sensory phenomena,* such as seeing, hearing, tasting, and so on; some study thinking and problem-solving. It should be clear that, in a way, this is a form of cross-sectional psychology. This is particularly true with regard to sensory response, which represents what an organism can do at a particular instant in time (in its life span), under specific conditions.

The study of sensory processes began when psychology was preoccupied with *consciousness* and *mind*, while motor phenomena were given little attention. In those days, if one had used the term "behavior" to indicate what psychology was studying, he would have meant only feeling, sensation, willing, and thinking. All these terms would have had a mentalistic connotation; they would have been attributes or activities of *mind*.

Since the advent of behaviorism as a school of thought in psychology early in the second decade of this century, motor phenomena have been included as behavior. In fact, behavior was taken by this school to be only such phenomena as could be observed by watching the organism as a subject. Behaviorism has now permeated psychology to such an extent that no one would be likely to eliminate motor phenomena as data. We now have two sets of terms, those that refer specifically to motor phenomena and those that refer to experience or sensation. In this book, both classes of phenomena will be dealt with, each in its appropriate way, without calling one class an expression of mind and the other an expression of something more tangible.

When we use the word perception in this book, we refer to the immediate response to a set of external conditions, or a set of internal body conditions, in which the mediating tissue is a sense organ.

PERCEPTION AND SENSATION

Many of the would-be distinctions between perception and sensation arise from preconceptions about and methods of the study of response rather than from the inherent features of response itself. For example, the early study of immediate response was concerned with the sensitivity of the organism. Generally questioned was how little energy an organism can respond to. Thus the study of thresholds was a central endeavor. The human is obviously sensitive to different kinds of energy and the impingement of this energy elicits various classes of experience (or consciousness). It was recognized that body structures and body processes are involved in this sensitivity to outside energy. The question thus arose as to how many body systems there might be. Aristotle, centuries before, had talked about senses, and without the aid of any instrumentation he had designated five. Now, with much more knowledge about body structure and process, it was supposed that there might be more than five sensory systems.

Finally, certain criteria were established to aid and systematize the search for sensitive systems. Evidence for a separate sensory system required the following criteria: (1) isolation of a unique class of experience, (2) isolation of a unique class of body structures, called sense organs, (3) isolation of a unique class or range of energy manifestation that would activate the sense organs, and (4) isolation of a distinct neural pathway from the sense organ to the brain. Much effort went into the use of these

criteria to determine the number of senses possessed by humans and other higher animals. In many cases the criteria could not be applied in a satisfactory clear-cut manner to determine whether a given supposed sense was only one sense or two. For example, the problem of whether we have only one temperature sense or a sense of warmth and a sense of cold arose from the fact that warm and cold neural pathways from the skin to the brain have some distinctness and the feeling of warmth and the feeling of coldness are quite different. Nevertheless, opinion has been that the temperature sense is one. To arrive at this conclusion from the many questions it raises has involved the unifying fact that the manifestation of energy being responded to for both warmth and coldness is *thermal*. Be all the doubts as they may, it can be said that there has long been an endeavor to relate as closely as possible input energies to sense organs, to body processes, and to specific classes of sensory end result.

While this has been going on, the old question of what is sensation and what is perception has been regarded as a natural one, calling for some solution. The two terms sensation and perception have been in use for some decades and knowing what they mean and how they are used is fundamental to our purposes. There are four principle views regarding their meaning, involving the following issues: (1) Do these words refer to the same phenomena in such ways as to be considered synonyms? (2) If not, are the activities referred to entirely distinct, so that to talk about sensation is in no way to talk about perception? (3) If they are connected functionally in some way, is one a forerunner or basis or component of the other? How such questions as these have been and are being dealt with will emerge from descriptions of the four views, which may be given the following labels: (1) the *historical* or *atomistic view,* (2) the *indeterminate view,* (3) the *separate-event view,* (4) the *unitary view.*

The atomistic view

In the atomistic view sensation and perception refer to two supposedly naturally distinct phenomena. Sensation refers to qualitative experiences such as hot, cold, red, green, rough, smooth, but they are not presumed to be experiences that refer to objects. Response to a stimulus as an object, such as a red apple, is thought to bring in meaning and the response is a perceptual one, not simply a report on sensation.

The atomistic view is an expression of the more general doctrine that mind is composed of elements much in the fashion that chemical substances are composed of elements. In the days when the atomistic view was fashionable, elements were irreducible. The mental elements of that time were sensations, simple images, and simple feelings. Perception was defined as "sensation plus meaning." However, experimentation that was meant to distinguish between sensation and perception failed to substan-

tiate a distinction, and the rigid atomistic view of sensation died with the demise of the atomistic view of mind. The way was open for other views.

The indeterminate view

The most characteristic thing that happened in the thinking of psychologists was retention of the two terms sensation and perception without making it quite clear what each is or how they are related. It is not a constructive view, and it is labeled "indeterminate" simply to indicate that abandonment of the two terms was not complete. In recent years, a new interest in perceptual response has developed and two additional views have emerged.

The separate-event view

This is a well-spelled-out view (Gibson, 1966), separating sensation and perception quite definitely by talking about sensory systems and perceptual systems as distinct. It contains a number of features that can be listed. (1) Sensation is passive; perception is active. (2) Sensations need not occur for perception to occur. (3) Sensation is an experience; perception is a use of information. (4) Perception involves the use of several sensory neural mechanisms. (5) No distinction is made between a receptor and a sense organ. (6) Proprioception and perception are distinguished. In other views, proprioception is a kind of perception. (7) There are but five systems of perception (general orientation, looking, listening, touching, and tasting-smelling). (8) There is no well-established number of sense modalities.

The descriptions of perceptual systems expressed in this view could have been made without much of this precise information and so they carry the implication that biological investigation of the sort alluded to is hardly necessary for the development of an adequate psychology of perception.

The unitary view

This view makes no distinction between something called sensation and something called perception. It assumes that the kinds of entities one derives are a function of the mode of analysis and the presuppositions of the analyzer. It recognizes that to hunt for body mechanisms and to correlate certain behavioral end results with them is one form of analysis, that to determine the broader relations between the behavior of the organism and the complex situations in nature that it encounters is a very different analysis. It is easy to see how the products of one form might be called sensations, the products of the other perceptions. But to make a categori-

cal distinction between the organism's behaviors in the two cases misses the point, misses what seems to be the central issue in the organism's immediate responses to the environment.

The central issue is: *How are the organism's various relations to the environment expressed?* This is to ask what kinds of interrelations there are. All the phenomena that we deal with are reactions brought about through the media of body systems called sense modalities. Questions of simplicity or complexity of response and the number of body systems involved at any instant are secondary. As Gibson holds, the analysis and isolation of body systems has disclosed many overlapping features between them. The unitary view simply says that if one wishes to see how closely he can correlate the response of the organism on any occasion with the activity of a single body system (a sense modality), he may. When he does so, he leaves out part of what goes on, for other systems are active at the same time as and in conjunction with the system studied. When he calls the behavioral result sensation, as though he were isolating a species of action different from perception, he is being too arbitrary and artificial. When he is frankly studying perception, he is admitting that his phenomena are the products of several sense modalities acting together. Gibson makes this admission. In this respect, we would both be studying perception. Even in the attempt to isolate a single modality's involvement in a sensory outcome we are still studying perception because we cannot get the organism to act as an organism below this level, even though our attempt at restrictive analysis leads us to think that we have something unique and naturally separable from the product we get when we intend to study perception. Thus it is misleading to call the behavior on one occasion sensation and the behavior on another perception.

The unitary view recognizes that the organism is not always doing the same thing as impingements occur and thus will not always utilize the impulses coming in from the sense organs in the same way. Instead of envisaging the differences as two, *passivity* and *activity*, it recognizes three general states of the organism.

1. A passive state, more frequently called fantasy, meditation, daydreaming, or something similar is the first state. In it the ongoing activity of the organism is not testing, questioning, or using the environment but is ruminating about past or future events. This is to say that there is a degree of disconnection between the organism and the environment. Among the few active overt processes carried on is maintenance of posture.

2. The second is an active motor state in which ambiance and alert instant-to-instant shifts in motor behavior are the prime objective. This is exemplified by the players in a football game. The information coming in by way of the sense organs is utilized, and even here various features of input that have to do with esthetic appreciation and the like are ignored or

given minimal attention. The reactions that occur, though motor, are included in what this view calls perceptual response. Thus, the unitary view makes no categorical distinction between what is motor and what is conscious, as did the atomistic view and even the separate-event view. In other words, the unitary view makes no distinction between perception and action. Actually, at times, the only response evoked by the sense-organ input is motor, but it fulfills the definition of perception as truly as does a discriminatory experience, which is more commonly called perception. Here it is appropriate to recall that in early modern psychology, motor phenomena were largely left out because it was supposed that psychology studied mind and consciousness.

3. The third state of the organism is the appreciative state, the state in which qualitative features of the environment are utilized for the enrichment of the individual. Whereas reactions of lower organisms seem to be confined to that which is nutritional, motor, protective, and the like, the relations of the human organism to the environment go far beyond these. In fact, the human is able to create new relationships, alter his environment, fantasize advantages and threats, and express values of relation that come out only in feeling. Perception plays a role in this process. In this third state, what we call the sensory impact or the esthetic is involved. Qualities such as color can be experienced in ways differing in level of significance and complexity. If we were trying to describe this pyramid of differences in terms of the other views, we would try to call some sensations and some perceptions. But there seems to be no logical or experimental basis for doing so since meaning of some sort exists at all levels.

The reader must be aware of the fact that the meaning of perception and sensation is, for many, still far from explicit. "Perception" is generally used when form and complex structure are involved; "sensation" is used when something less complex, such as color, brightness, roughness, or coldness, is referred to.

This book espouses the unitary view of perception, and hence it employs no sharp divisions between perception and sensation. It adopts, with qualifications and explanations, some of the procedures and outlooks of the day in order to report investigations in the literature.

This view introduces formally what is either overlooked elsewhere or only informally and implicitly involved—namely, the principle of *utilization*. Other views confine themselves to the stimulus-response paradigm. But no behavior occurs except by efferent innervation, which should be looked upon as a central nervous utilization of the residues of past confrontment and of the current inputs of sense organs.

Whereas the separate-event view makes much of the fact that perceptual response—response at the top level of integration—does not need to be built upon sensory experience as units, the unitary view sees the various

forms of response, from simple experiencing to complex or from motor experiencing to complex, as only the separate outcomes of utilization.

PERCEPTION AND MOTOR RESPONSE

There is still a tendency to confine the connotation of the word perception to that which is experienced rather than to include motor responses that are evoked by stimuli. To the extent that this textbook is biased for purposes of unity and integration of material, perceptual response is not confined to experiential response. Motor response is a legitimate and relevant form of immediate response to specific stimulation.

PERCEPTION AND REFLEX RESPONSE

Motor activity has traditionally been divided into two classes, voluntary and involuntary, or reflexive. The chief difference between them is that the latter is said to be genetically determined and more-or-less stereotyped and "ready-made." Reflex activity, like so-called voluntary response, is a form of reaction elicited by a specific stimulus situation. A close examination of reflex behavior discloses that it is not as stereotyped as at first supposed. The form of some reflexes varies with certain stimulus variables. It is quite certain that some, if not all, reflexes are forms of discriminative activity and are therefore to be classed along with other motor responses. Thus, while such forms of behavior are still to be called reflexes, they satisfy our definition of perceptual response.

PERCEPTION AND THE RELATION OF THE ORGANISM TO ITS SURROUNDS

It is the view of this book that the purpose of studying either sensation or perception (if the two must be separately defined) is to determine and understand the relation of the organism to its surrounds, or environment. Organisms are viewed as as parts of and existing in nature; therefore, their behaviors are interactions with events in nature. Our present purpose, then, is to become informed about the ways in which each species can and does interact with nature.

The study of perception is not a simple, direct task of accumulating easily obtained and easily understood data. Man has no absolute starting point, since he exists in two "worlds," the energistic and the experienceable. He acts and thinks as though there were only one, the world he experiences. He cannot experience the energistic world the physicist describes and uses for all his laboratory operations to build his theories and develop a comprehensive understanding of the astronomical universe. Man is thus in the unique and peculiar position of having to lift himself by his own bootstraps.

He needs to know about his environment, the physical universe, and he needs to know about himself. He needs to come upon the principles that pertain to the interaction between the two. But, even as a physicist, he possesses no absolute knowledge of his environment. What he does possess regarding his surrounds has come by way of his own limited facilities—that is, his own sense organs, his own nervous system, and his own effectors, the muscles. Yet it is these very mechanisms that he wants to test and understand. So what can he do? He can do no better than to use the facilities he has, his own abilities to experience and conceptualize and make order out of his encounters. The physicists have used these capacities to construct ideas about the world that is independent of man. But the psychologist has the problem of dealing with man. In other words, he is faced with studying himself. He must deal with man in terms of his reactions to the physical universe, with the added supposition that he himself is wholly a part of it and not apart from it. The physicists talk about the physical universe exclusively in terms of energy and the principles whereby energy is transformed into its several manifestations: thermal, electrical, mechanical, and so on. The universe of the physicist is a nonexperienceable realm, but he must describe it in terms of the experienceable—that is, in terms of particles, wave motion, force, and the like. Despite his lack of absolute knowledge about the physical universe, the psychologist must use what he does know as the basic system in his inquiry about human behavior, because it is through the processes of behavior that communication between people is brought about. Because man obeys physical laws just as though he were a substance in a test tube or a retort, the psychologist faces a paradox even before he begins. He must recognize the position he is in and make as consistent use of his materials as possible.

The psychologist, in relating man to his environment, is obliged to start by considering man as an energy system. What the psychologist understands stimuli to be must conform to the physicist's understanding of them, and what the psychologist understands as the lower-order body processes must correspond to the biochemist's and the physiologist's descriptions of them.

The psychologist must build up an understanding of man as a person by observing his interactions with his surrounds. His observations must be worked into a conceptual scheme that makes a comprehensive, sensible, and self-consistent picture. He must do just as the physicist: He must make his own carefully considered interpretations of what he experiences. He is in a curious predicament, because it is his own ability to observe and perform that he is trying to analyze and understand. Because of these paradoxes and subtleties, the psychologist has been very slow in progressing toward his goal. He has made many blunders, and he has had to backtrack many times and move up new trails again and again.

DEFINITION OF PERCEPTION

Perception is the immediate discriminatory response of the organism to energy-activating sense organs. What can be called immediate and what cannot may seem quite clear from the commonplace meaning of the word, but taking into consideration the specific kinds of response we know the organism makes calls for a specific definition of "immediate."

Can immediacy be defined purely by setting a time limit, or must something else be included? Obviously, the perception of objects rapidly approaching the body or eye consists of brief avoidance reactions, involving only a second or less. There is no difficulty in calling these immediate. But there are many other occasions in which neither the external event nor the consequent behavior is limited to such short times. For example, when a person is asked whether two vertical strings suspended in front of him are equidistant from him, he does not typically react quickly and briefly. Even if the strings actually are equidistant, the observer may be far from sure. In fact, when such a question is asked, the observer generally attempts to be quite precise. Since he considers very small differences significant, he does not settle by a mere single glance how the strings look. He responds by taking several looks and by moving his head and eyes if allowed to do so. Even with very small amounts of such motion, the strings may shift their apparent relative distances from him. The matter does not stop at that. Reverses in relative distance may continue for a number of seconds before the observer arrives at a report to give the questioner.

The changing behavior we have just described is not to be considered a single unit of activity, or a single extended reaction, but rather a series of reactions, each of which can be taken as a unit and is called a perceptual response. Thus, before the observer is willing to make his report, or his terminal reaction, he makes a series of immediate reactions, each of which is called a perceptual response with respect to externality. When the observer comes to the terminal point, the reaction is called the expression of a judgment. Actually, the task given the observer was too exacting to be accomplished quickly by a single perceptual response. The observer spontaneously began the process of judging. The report given by the observer is called a judgment in conventional terminology, although it is also erroneously called a perception, as though the two words were synonymous. For us, the judgment is an integration of the several perceptions and of certain concepts and possibly of certain memories.

Other occasions differ from the one just described. Let us say that a person is asked to look steadily at what he perceives as a card on the wall opposite him and to observe its color for a period of a few seconds or longer. If the color of the card remains constant in hue, intensity, and saturation,

we can call the whole reaction a single perception. Since the experience, the crucial feature of the reaction, did not change, there is no reasonable means by which we could subdivide the reaction. Thus, in spite of its extension for a number of seconds in time, it is still an immediate reaction. It is a constant and it continues during the life of the impingement. What we have then, in the color experience, is a steady and direct relation between an extended stimulus and response.

To make clear what is meant by *discrimination,* we can say that *to discriminate is to make a choice reaction in which contextual conditions play a deciding role.* The cerebral cortex is the best example of a system that discriminates; hence, when we find behavior that involves cortical participation, we may arbitrarily class it as discriminatory. The determination of whether certain reflexes will occur or to what extent or in what contexts they will occur often depends on the cerebral cortex; such reflex behavior is therefore certainly discriminatory.

As an example of a nondiscriminatory reaction, we can cite the behavior of the mercury column in a thermometer. It behaves rigidly in accord with thermal conditions impinging upon it, without regard to past history, present context, or any other such potential consideration. An example of a discriminatory reaction is human brightness perception, in which the apparent brightness of a disk of light depends not only on target intensity but on the luminance of the area around it, on the target area, and even on other considerations.

Discrimination seems to be an apt term in describing an ongoing system, a system whose action is describable as directed toward goals. Such systems possess a particular form of organization and the "choice" reaction already mentioned is determined by the characteristics of this organization. In such systems, there is often if not always feedback, by which a constantly adjusted approach to a goal is effected.

CLASSES OF PERCEPTUAL PHENOMENA

Despite all that has just been said regarding the inclusion of motor reactions in the definition of perception, most of the experimental work that has been done on perception has failed to include it. Perception is in most cases assumed to be sensory experience. Perception of this sort possesses six broad aspects.

1. Perception involves a qualitative aspect—that is, one class of perception is differentiated from another, such as sights, sounds, tastes, smells.
2. Perceptions involve shape, outline, and grouping, according to Allport (1955). Allport seems to be referring not to all senses but more particularly to what is seen; the examples he gives are restricted to visual and auditory experiences.

3. Perceptual response amounts to being a classificational response. The number of differences in pattern, identity, size, shape, and so on that the organism detects is decidedly smaller than the differences in the energistic inputs reaching the sense organs. A piece of paper seen as white in broad daylight is taken to be the same piece of paper when seen in moonlight, although the input to the eye is much reduced in intensity. This is spoken of most often as *perceptual constancy*.

Actually, there are two matters involved in so-called constancy. One is *identification;* the other is *quantitative appreciation*. While the sheet of paper is taken to be the same, by reason of somehow looking the same, no observer would declare that the surface of the sheet looked equally light in daylight and in moonlight. What the perceiver is doing is identifying the paper, and this includes more than dealing with the intensity of reflection to the eye in the two cases. This performance is called lightness constancy; it could also be called correctness of identification. In other experiments, the question of how light the paper's surface looks is at issue, and experimental procedures are employed to determine how different the reflection to the eye from the paper can be in two cases and yet have the two seen as equally light. Here we could more appropriately call the behavior an expression of lightness constancy.

4. The fourth form in which perception can be expressed is in absolute terms. The perceiver may be asked to respond as to whether something sensed is bright or dull or light or heavy and so on. This is very different from perceiving two surfaces as equally light or two objects as equally heavy or one as heavier than the other. No concrete reference stimulus is supplied, but the observer can nonetheless make a response. The perceiver forms or possesses his own reference, or dimensional frame-of-reference.

5. What we experience possesses concrete object character. We live in a world of *things*, things of our own making.

6. The sixth characteristic of perception is spoken of by Allport as the effect of the *prevailing set* or *state*. In other words, the perception is a characteristic not only of the species but also of the individual at the *time* of stimulation.

PHENOMENOLOGY

A great deal of sensory response, as already mentioned, consists in experience. Many experiences are experiences of objects and other entities that, as a class, are called phenomena. Allport states that any experiences reported upon as to how they "appear" as in contrast to how they "are" are called *phenomenological*. The procedure of observing and reporting such experience is called the *phenomenological method;* it has also been called *introspection*. The topic, as a whole, is called phenomenology.

STIMULUS AND IMPINGEMENT

It has long been customary to use the term stimulus in a supposedly technical way. Whatever it has been thought to be, it has of course been distinguished from a set of events that seem to be a consequence of its existence, events that have been called responses. Once one begins to use the word, he may be called upon to indicate what it refers to—that is, how it is defined. As a consequence, various men have defined stimulus in different ways, with different degrees of exactness, and not one but several definitions have come into being. Furthermore, it is seldom apparent just which definition, or connotation, is being used by a writer at a given time until one has followed along far enough to make one's own inferences from the context.

Among the defects in usage of the term stimulus has been the fact that, in most cases, usage provides for some stimuli not to stimulate. One would think that a stimulus is something that stimulates, but according to this view he finds that some do and some do not. This paradox is generally dealt with by inserting the idea of subthreshold stimuli. Several subthreshold stimuli may sum (that is, add together) and become effective in eliciting a response.

There seems to be a better way of dealing with the paradox. One may employ such a term as *impingement,* particularly since we have implied that the stimulus is some sort of energy that reaches sense organs. By definition, an impingement is the energy reaching a sense organ. There is no implication regarding consequence, as there is in the term stimulus. A stimulus stimulates, or elicits a response. An impingement is simply energy that reaches the sense organ.

It follows then that some impingements elicit responses and some do not. Those that do are stimuli. Stimuli are thus species of impingements. All stimuli are impingements, but not all impingements are stimuli. The behavior of the system impinged upon is the evidence of stimulation. In some cases, it does not seem necessary to have made the objection to the traditional usage of the word stimulus, but in others it provides for clarity and certainty in communication that has long been lacking.

A CAUTION ON USAGE OF TERMS

The minimum number of categories that is implied in experimental psychology is two; the stimulus (impingement) and the response. Each of these categories requires its own vocabulary. When referring to the stimulus or "input," one must use terms that apply to it and not to the response and, likewise when one is referring to the response, terms applying only to it must be used. This caution would seem to be unnecessary, but in fact one

finds many violations of the rule. For example, in discussing vision one often sees the word "light" used both for the impingement and for what the perceiver sees. The word "flash" is used in both categories; thus, a flash causes a flash. In this book "photic radiation" supplants the word light as a stimulus or impingement term. "Pulse" or "photic pulse" supplants "flash." Thus, light and flashes are what one sees. Photic radiation is what elicits visual experience. A brief input of photic radiation is a photic pulse, and the experience elicited is a flash. Many other examples of double talk are to be found in the literature.

When dealing with stimuli and sensory end results (responses) as well as with the intervening body processes, a third vocabulary or set of terms is necessary. Words must be employed that refer to the body processes and not to either of the other sets of items. Following is an example of this principle carried into three categories.

In describing what one sees, the word "edge" is often used. If one describes the target [1] at the same time, he might find a word other than edge to use. One might call this characteristic of the target its border. If he goes further and deals with the intervening body process responsible for seeing the edge, he is not at liberty to use the word edge because, first of all, he is dealing with a category different from vision itself and, second, he is dealing with a process, which is not likely to have edges. A more appropriate term might well be *contour-process*. When one uses this procedure, then, it is apparent at all times exactly what is being referred to. Without it, one does not have the means to communicate, at least not without considerable parenthetical explanatory injections.

THE CONCEPT OF TARGET

One finds that an exclusively physicalistic (energistic) description of an impingement is not always available, or perhaps it is not understood by anyone except a relativistic physicist, who deals with quanta and the like. Hence, we are often compelled, for the sake of consistency on the one hand and effectiveness on the other, to use what may be called a neutral term. In vision, for example, one speaks of a target, which seems to be the stimulus but, since it is not the photic energy itself, it is not the stimulus. The target is what the experimenter or anyone else may see—that is, it seems to be what is presented to the subject or observer to report upon in an experiment. Actually, what stimulates the observer is the photic energy that no one sees. But what the observer describes may or may not tally with its standard description. Whether it does is one of the matters at issue in an experiment. This issue is associated with whether the observer's response is what one would expect from the known energistic features of the photic

[1] See next section for a definition.

input. These features are the intensity and spatial distributional characteristics as described for the target. It is possible that someday we will have advanced far enough to be able to use completely energistic descriptions of impingements and then the neutral item, such as the target, will be totally unnecessary. For now, it provides an approach closer to consistency in what we say than if we say first that stimuli are forms of energy and in the next instant describe them as something seen, or responses.

COMMUNICATING REACTIONS

If the experimenter wants to get at an experience, then a communicating reaction of the observer must represent it to the experimenter. This reaction may be in the form of either a predetermined motor response or a verbalization.

The degree to which the communicating response represents a perception may vary, and it is incumbent upon the experimenter to take this question into account in his experimental design. In fact, it is incumbent upon psychology to make a point of studying this very question directly, for it is of major significance.

This problem was involved in the suspended-string experiment given earlier. In it we said that the overt indication the observer gave the experimenter was a judgment. The terminal response stemmed from a number of perceptions. If we can accept the judgment in each trial as a selected perception, then we can use the judgment to deduce what perception is like. If, however, such judgments contain biasing ingredients that the observer wittingly or unwittingly injects into them, then judgments do not very well represent perceptions. The discrepancy may well vary from observer to observer. Extraneous factors are more likely to enter into the reactions of naive observers. One of the greatest desires of a naive observer is to be "right"—that is, to act in such ways as not to come into conflict with physical externality or custom. This is a natural and understandable tendency, since survival requires him to be "right" in all his everyday encounters. For example, when a fan is revolving rapidly, the blades are not observable as blades. They may be perceived as a color film, and color films may look as though one could extend one's hand through them, since they do not seem to be solid. In such cases, it is important to utilize all possible criteria to determine whether to extend the hand and a number of factors are taken into account in addition to the mere visual appearance of the film area itself. But the attempt to be "right" is carried over into laboratory behavior and often runs counter to laboratory instructions and invalidates the experimentation.

We are not without concrete information regarding the difference between perceiving and judging. The following experiment is an illustration of how the outcome may differ when exposure time is varied. Two different

exposure durations of tilted circular targets (stimuli) were used, 0.01 second and 1 second. Obviously the first is quite short, not allowing for much eye movement, if any, whereas the other is reasonably long. It would be expected that the reaction or response could be called perceptual when the shorter exposure was used, since the observers were given no opportunity to utilize more than one relation between themselves and the target. That is, they could not take several "looks" at it and use them in a combined way to arrive at a conclusion; they had only the single brief encounter. When the target exposure was more than 0.01 second in length, considerably more time is allowed, during which more than one "look" can occur. In other words, eye movement is provided for. When eye movement occurs, more than one kind of contact between the organism and its surrounds can and most always does take place and thus more than one perceptual response occurs.

Leibowitz, Mitchell, and Angrist (1954) found that with the shorter exposure the responses indicated one thing and that with the longer exposure they indicated a very different organism-target relation. More specifically, the reaction to the short exposure followed the law of the retinal image, and the reaction to the long exposure followed the law of shape constancy. With long exposures, the tilted circles looked like tilted circles; with the short exposures, they looked like ellipses. Hence it can be seen that not all experiments in which judgments are provided for bring out what perception is like. Thus, if the longer reaction is a judgment and the shorter one a perception, it can be said that we have an example in which they differ radically.

A LIMITATION OF FORMAL EXPERIMENTS

Certain kinds of experimentation often contain repetitive elements, which may make them learning situations. On the other hand, they may be situations in which the observer develops concepts or guesses as to what is being presented. These "constructs" of the observer may then enter into his reactions and may either distort or totally invalidate an experiment. Let us take an example.

Suppose a set of luminous cardboard disks is presented to an observer in a dark room for the purpose of determining their perceived shapes or of determining the positions in which the seen objects seem to lie. Let us say that there are three differently shaped ellipses and one circle. Let us say that each of the disks is presented in one or the other of three positions of tilt in random order. This set of variations is limited and must be repeated several times for the experimenter to gain the information he wants. In part the experimental trials are like a natural set of conditions and in part they are not; for, in the common run of everyday life, disks may vary a great deal more than these in shape and position. Outside the laboratory, the

individual has to take each case by itself, but in the experiment the limited number of variations are repeated over and over many times. During this repetition, the observer may detect similarities in trials even though random variation is involved, and he begins to stereotype his responses. He may say to himself, "Ah! This presentation is like one I had a moment ago. How did I respond to it? I must be consistent. I'd be foolish to respond differently to the same disk from trial to trial." This reaction would run counter to the instructions and intentions of the experimenter. The experimenter desires a response determined solely by what the observer can immediately make of the limited sense material of the moment, rather than a response that stems from an attempt to conceptualize or guess about the plan of experimentation.

THE PLAN OF THE BOOK

There are two approaches in dealing with perception. One is to study the various separate sensory mechanisms of the body and relate their function to stimulus input and to sensory outcomes (stimulus-body process-behavior) largely determined by these specific processes. The other approach is to describe the organism's environment so as to indicate what it is that the organism encounters in its daily affairs. The first approach indicates what the organism, by way of its body mechanisms, is able to make of the energies reaching its separate types of sense organs. It is a description of the experiential world developed through contact with the environment. The second approach does not consider the sense modalities as insulated from each other but deals with the organism's contact with several sense modalities in the environment that cooperate to make the behavior what it is. For example, instead of dealing with the senses of touch, the vestibular sense, and the muscle senses separately and in terms of what each involves, the second approach deals with the organism's basic mechanical orientation to environment, as in the maintenance of posture and in effective locomotion in the gravitational field. While the second approach may in a way be more superficial and less analytical, it is less artificial. The two approaches complement each other and both are necessary.

This book utilizes both approaches. One is used as a preparation for the other. Most of the book is description of the nature of the separate sense modalities, one at a time. As this description unfolds, the interrelations of the senses are dealt with. These interrelations are taken up more comprehensively in the final chapter.

The book is in six parts. The second and last chapter of Part 1 is on development of perception. Part 2 presents some of the basic facts of vision, including the neural mechanisms operating in the optic pathway, the neural pathway from the retina to the brain. The assumption underlying the presentation of body mechanisms is that knowledge of them helps in under-

standing vision. Many sensory end results are not understandable as consequences of the photic input to the eye until one learns how this impingement is processed. The processing, or the succession of effects, is determined by the nature of the neural mechanisms involved. One cannot be satisfied with wholesale imputations or guesses regarding what the brain does. He must first find out what is delivered to the brain by way of the optic pathway.

Part 3 deals with visual perception, which includes perceptual constancies and the perception of space, figure and form.

Part 4 moves to the consideration of hearing, which includes certain basic facts regarding auditory body mechanisms. The second of the two chapters in this part deals with auditory perception.

Part 5 presents facts and principles regarding the remaining senses, which include the senses of the skin and kinesthesis (the muscle sense), the vestibular sense, and taste and smell. Since far less is known about these senses, they require less discussion than vision and hearing.

Part 6 is devoted to perceptual change. While the development of perception is dealt with in Chapter Two, the changes described here have to do with perceptual learning, with perception dependent upon social interaction between individuals, and with the fact that perception is by its very nature symbolic rather than pure representation.

It is to be understood that the subject of perception is too vast to be covered exhaustively in a single volume and that, as a result, considerable selection of topics and experimental illustrations is necessary. If as a student you do not find certain topics or illustrations you may expect, perhaps you can deal with them by asking questions in class.

SUMMARY

This was an introductory chapter and had a number of tasks to perform. It identified what is to be called perceptual response by making a distinction between psychological approaches that characterize the individual in temporally *longitudinal* terms and approaches that relate him to the *immediate* physical conditions at the time.

The chapter pointed out the conventional criteria for isolating sense modalities and the various ways of distinguishing what is called perception from what is called sensation.

It pointed out that the description of perception is dependent upon the state or mode of existence of the organism. In this connection, three major states were described.

Since perception was defined as an immediate expression of the relation of the organism to its surrounds, it included overt response as expressed in muscle activity, as well as conscious reactions.

Six classes of perceptual phenomena as designated by Allport were described.

Certain cautions and principles in the development of technical and scientific language were given, a major feature of which was the distinction between terms for stimulus and response.

Certain characteristics of appropriate experimentation on sensation and perception were given.

Finally, the overall plan of the book was set forth.

TWO

The Development of Perception

We are about to deal with two major problems in the general realm of perceptual achievement. The first is *development;* the second is *adaptation, adjustment,* and *learning* as they are found in the mature organism.

Study of development follows a given individual or a given species through a time span to determine growth in achievement. This growth is possibly largely an expression of maturation or anatomical and body-process development. Since no organism develops or even exists in a vacuum, the fact of stimulation is to be reckoned with.

The second problem, that of adaptability once maturity is reached, is in so many ways similar to the first that a degree of arbitrariness is involved in separating them. Many investigational examples are suitable for describing both. One of the more easily made distinctions reserves the studies on adult organisms as examples of adaptation and uses all others to exemplify development. However, this overlooks the fact that many times the study of development is comparative, dealing with the relative perceptual abilities of adult animals at various levels in the phylogenetic scale. Even so, this seems to be about the most workable distinction to use, and therefore it will be used, with one exception, in determining the material in the present chapter and in Chapter Fifteen on perceptual learning and change. The exception is that when preadult subjects in perceptual learning experiments are described, the investigation must focus on the learning and not simply be a demonstration of the general perceptual status of the species. Studies dealing with the general status of the immature subject are still to be taken as parts of the story of maturational development rather than the modifications we call learning and adaptation.

THE COMPARATIVE PICTURE

Perception up and down the animal scale

The lower animal forms begin life as more or less complete, possessing at birth or soon thereafter all behavioral manifestations they will ever exhibit. The higher animal forms, on the contrary, pass through an extended period during which their anatomical mechanisms develop. With this develop certain subtle capacities aside from the directly observable changes in anatomy. Both aspects of growth taken together are called maturation.

In studying perception in lower animal forms, it is often necessary, or at least convenient, to use learning experiments, which consist in trying to get the animal to discriminate one stimulus from another by repeated presentations and reward. Aside from the information obtained regarding learning, the behavior may indicate the nature of stimulus manipulations that are necessary for perceptual discrimination. That is, the manipulations may be arranged so as to demonstrate the minimal differences between stimuli that can be discriminated. Hence, it should not be surprising that we cite certain animal experiments that seem like learning experiments, for some of them have demonstrated something about the animals' perceptions.

EARTHWORMS. Earthworms have been trained to make consistent right and left turns in Y-shaped and T-shaped mazes as an example of their ability to perceive the difference between the two shapes. The habits of the turns can be reversed and reversed more easily than they can be learned in the first place. This seems likely to be due to having set up conditions in which the kinds of stimuli used by the experimenter have become prepotent.

MOLLUSKS. Mollusks have been conditioned to make T-shaped maze discriminations. The experiment ran as follows. The unconditioned stimulus was lettuce touching the mouth region. Pressure on the foot was the conditioned stimulus, prepotent over the mouth-opening stimulus. After approximately two hundred and fifty trials, the conditioning was accomplished; by this time, mechanical pressure, when given alone, had come to elicit opening the mouth. It took only twelve trials to extinguish the response, but it was quickly relearned. One sees the same principles at work as are demonstrated in much higher animal forms. Perceptions—that is, discriminatory responses—do take place, and they are subject to learning. The mollusk can learn to do something opposite to the behavior that appears to be a more-or-less simple and stereotyped form of inherited behavior.

ANTS. Ants—representatives of the arthropods, or particularly the insects—are capable of learning their way through long intricate mazes. In many respects their performance is not inferior to that of mammals and is even better than in many of the lower vertebrates.

VERTEBRATES. Among the vertebrates, the reptiles seem to be better than fishes and amphibians (frogs and so on) in maze performance. Fishes such as goldfish have been taught to discriminate between various levels of illumination in a series of compartments to which they were free to swim. This behavior was truly configurational and thus was in every respect discriminational. The fishes could choose between greater, medium, and lesser intensities regardless of the general level of illumination.

Fantz (1954) used newly hatched chicks as his subjects to study form perception. Fantz points out that chicks can indicate more directly what they see than many higher animals can, for soon after leaving the shell they set out to get something to eat. They peck at certain things and avoid others. Accordingly, Fantz's chicks (one thousand or more) were tested on about one hundred different visual targets. To begin with, the chicks were hatched in unilluminated quarters and the tests were made at the very first exposures to illumination. When presented with eight items varying from roundness to angularity, they pecked ten times more often at spheres than at pyramids. When flat targets were presented, circles were preferred to triangles. Among the circles presented, those ⅛ of an inch in diameter were preferred most often. Furthermore, the chicks pecked much more often at spheres than at flat disks. The experimenters concluded that the chick possesses an immediate ability to perceive shape, size, and three-dimensionality.

Certain experiments regarding space perception in domestic fowls were made by Katz and Révész (1951) and by Révész (1934) that are both interesting and instructive. Fowls feeding on grain and other small objects plentifully strewn about will cease pecking when the illumination drops below a certain level of intensity. This is taken to indicate that the pecking response is in some way dependent upon vision. In darkness, the rattle of falling grain, which tends to excite fowls when they are under illumination (that is, it induces definite overt reactions), leaves them outwardly inert.

Révész (1934) points out that although a hen may run about to examine its surrounds and scratch and otherwise search for food, it does not stay and search at a spot where it has seen food hidden. Thus, in this respect too it seems to be entirely a visual animal. The behavior of fowls toward hidden food objects shows that either they do not possess visual imagery, or representations, at all or, if they do, the visual imagery is not such as to be usable as "motives," or means toward definite action. The hen never seems to profit by single experiences; an accumulation of experiences is required before she can make anything of experience. This

seems also to be evidence that visual imagery, or any other sort of imagery for that matter, is not very serviceable even if it exists. Révész tried various conditions under which he hoped to get his experimental hens to go after hidden grain, covering it first with transparent material and later with opaque, but otherwise leaving it with the same visual characteristics. The hens pecked at the transparent material but could not reach the grain. With the opaque material the hens were inert. Révész tried covering part of the grain and again the hens would not do anything more than peck at and eat the visible grain. This is of course in contrast to the behavior of mammals such as monkeys or dogs, which would have tried to get the hidden food first. Repetition and some happy accidents in which the hens did push the covering material slightly aside and get some previously covered grain led to some learning; the hen did finally come to exert some effort to uncover the grain. In the end (that is, in relatively few trials), the hen came to the point of pushing anything aside that covered the grain. Hence it could be said that hens are capable of learning to uncover hidden food in specific situations in which a series of practice trials is assured. But, as Révész puts it, the animal must be actively and continuously engaged in reacting to optical stimuli for the achievement to develop.

In a very different situation, in which Révész covered the grain with a pane of glass, the hen could not be induced to try to push the glass away. The sight of the grain through the glass was so compelling that the only reaction inducible was that of attempting to reach the grain through the glass.

Révész analyzed the pecking behavior of the hen into *aiming, quick movement* of the head, and *picking up* the grain. Pecking does not occur without aiming, and aiming cannot occur except toward visible objects. This explanation seems to account for the hen's failure to peck in the dark. Not only is aiming necessary, but a certain distance or positional relation of food and head must exist for pecking. Révész has called this distance the *pecking elevation.* When the experimenter places the beak of a hen in a basin of grain, the animal does not eat. It seems unable to do so. Apparently it can eat only when the head can assume a position at a necessary distance from the grain. This interesting analysis of behavior has been carried further, but we are forced to pass on to still other features of and conditions for the hen's visual perception.

Another set of experiments by Révész showed that hens left for several days in the dark did not consume a single grain of the food left with them. There was some evidence to indicate that methods could be devised to train them to consume part of or all their usual supply of food in the dark. One experimenter has reported special conditions under which pecking and obtaining food did occur in the dark, but it is not clear just what these conditions were.

Révész trained hens to discriminate between the smaller of two plane geometric figures such as circles, rectangles, triangles, and squares. After certain behavioral criteria had been reached, the investigation passed on to use of the geometrical "illusion" called the Jastrow illusion (Fig. 2.1).

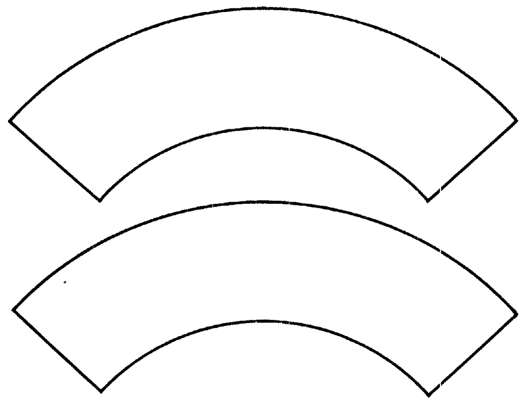


Fig. 2.1. Jastrow illusion. Although the two sections are equal in size, the bottom one looks larger.

For the hens the two portions of the target were placed in various positional relations to each other and they were made metrically unequal. Choosing the smaller of the two was the performance learned. After this preliminary training series, in which the hen procured grain from the proper one of the two target elements, the target elements were made equal in size and positioned so that a human observer would perceive them as unequal. The problem was whether the hen would choose the perceptually smaller target element. If it did, it would indicate that the hen was, in effect, subject to the Jastrow illusion. The test turned out positive, and it was concluded that perceptions of the hen certainly did not tally with the actual size of the targets but were something like the human's in such situations.

Rearing animals in restricted kinds of illumination

Perception by definition is described in terms of immediate achievements upon confrontation with the environment. If a species is able to react effectively at birth to sensory impingements, little or nothing can be determined about its mechanisms of perceptual *development*. But if one can trace from the earliest rudimentary reactions to later, elaborated effectual responses, he may gain insights into the mechanisms involved. For these reasons—including the possibility that development and adaptation

involve the same mechanisms—we will consider studies that deal with the earliest beginnings of perceptual response.

Riesen (1960) reared chimpanzees in environments devoid of illumination and then tested them at various periods in their early growth to determine their visual abilities. He discovered that withholding photic stimulation caused some retinal deterioration, which interfered, of course, with his intended data-collecting. In a later investigation, instead of darkness he used a homogeneous (that is, unstructured. illumination over the entire retina, called a Ganzfeld; it provides no stimulus basis for form vision and space perception. The chimpanzee reared under these conditions showed considerable immaturity when tested at the age of 7 months in an ordinary environment, and it only gradually learned to follow moving targets with its eyes. Riesen interpreted this as evidence of retarded form perception.

The fact that the animal only gradually learned to follow moving targets does not mean that the newborn animal of the same species could not follow visual targets. Retrogression in muscle performance brought about by lack of appropriate retinal stimulation during the photic restriction period may have been the basis for the poor visual pursuit performance.

Not all deprivation experiments on chimpanzees have involved studies of vision. Normal tactual experiences were precluded in some animals studied by Nissen, Chow, and Semmes (1951).

Visual deprivation

Interest in perceptual change does not stop with the mere discovery of the kinds of perceptual behavior changes but includes attempts to discover body mechanisms that provide for and underlie them. Many studies do not go this far, but in the investigation by Wiesel and Hubel (1965a, b), the behavior of the cells in the visual cortex was of prime interest.

Kittens that had one eye closed by suture from birth to the age of about 3 months were tested for the reaction of single cells in their visual cortex. In normal animals many cells in the visual cortex typically respond from the time of birth to the illumination of both eyes. The cortices of the deprived animals, in contrast, possessed a preponderance of cells that reacted only to the illumination of the eye that had not been sutured. In kittens with both eyes sutured at birth, some cells responded bilaterally but many cells responded atypically.

Wiesel and Hubel attempted to discover the extent of recovery after opening the sutured eyes. They found that the ability to recover from the effects of deprivation of both one eye and two eyes was severely limited for over a year whether judged by behavior, by cell structure, or by the physiological reactions of the cortical cells tested.

Not only sheer deprivation—that is, not allowing the kittens to "see

form" for their first three months—altered the physiology of the visual system; so did the experimental production of strabismus, or cross-eyedness (Hubel and Wiesel, 1965). In four kittens, strabismus was produced shortly after birth, and later electrical responses of the visual cortex were tested. Whereas in the normal animal about 80 percent of the cortical cells can be activated by both eyes, in the strabismic kittens the percentage was reduced to 20 percent. Quite similar results were obtained by alternate occlusion of one of the two eyes. The occluder was changed from eye to eye once a day. The cells of the visual cortex seemed to fall into two groups, those reacting to one eye and those reacting to the other eye. However, the animals did not evidence any detectable behavioral effects. The experimenters concluded that strabismus causes cortical cells which are especially responsive to shift from one eye to the other.

The visual cliff

The next type of experiment we turn to is the work with the visual cliff, an apparatus devised by Walk and Gibson (1960), as shown in Fig. 2.2.

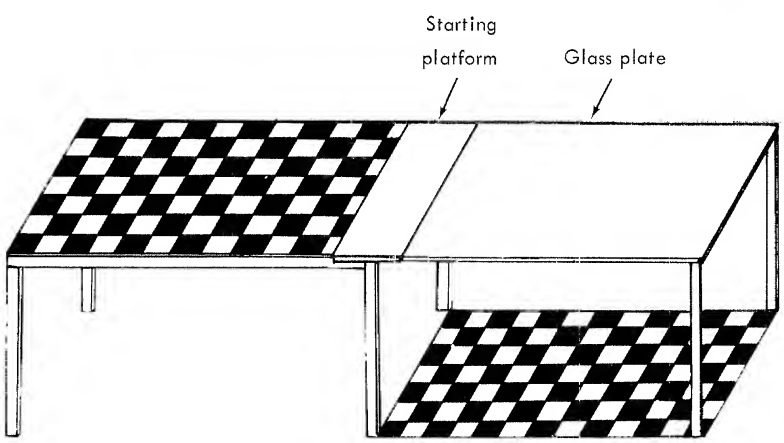


Fig. 2.2. Visual cliff. A visual cliff has two figured surfaces and a starting platform. One surface is at the platform's level; the other is some distance below as, for example, at floor level. On the side of the starting platform opposite the figured surface is a glass plate. An infant or animal is coaxed to move onto the plate, but it generally refuses because the surface seen is the figured surface below and the arrangement of the materials creates the illusion of a cliff situation. Side boards are often used around the whole apparatus at the platform level to exclude extraneous visual stimuli.

A huge horizontal plate of heavy glass is supported about 2 feet from the floor. On the underside of half the plate is glued a checkerboard design visible from above. Below the other half the same checkerboard design is placed on the floor. In some instances the design may be left free for raising and lowering for certain distances from the floor. Across the plate at the juncture between the two halves is a platform board on which the subject—a small child or a small animal—is placed. As one would expect for adults, the arrangement presents an apparent drop-off cliff on the side of the board where the design is on the floor, and, if the two checkerboards were the only surfaces involved, one would expect to fall over the "cliff" if he moved off the board on that side. Of course, the glass prevents this, the experimental subject actually being able to move out onto the glass "in midair" with impunity.

In this sort of investigation, the experimenter relies on the overt behavior of the subject to provide information on the subject's vision. Walk and Gibson used chicks, lambs, kids, rats, turtles, kittens, dogs, and pigs as subjects. In each case, they were able to conclude something about the role of vision in the life of the species. They found that depth perception showed itself quite quickly. Chicks less than 24 hours old never hopped off the board on the cliff side. Kids and lambs, tested as soon as they were able to stand, never stepped off the board on the cliff side. Placing them on the glass on the cliff side caused them to display characteristically resistive behavior; as they were placed there, they would not put their feet down and took a defensive posture. Some were pushed across the glass on the cliff side toward the board until their field of vision crossed the edge of the board; at this point, they would relax from their rigidity and spring toward the board as if to reach safety.

A quantitative variable was introduced in the case of the goats and the kids. The depth of the visual cliff was varied by raising the checkerboard pattern from the floor toward the glass by desired amounts. Dropping the checkerboard lower than one foot from the glass brought on the defensive reaction, while distances closer to the glass provided for free movement of the animal on the glass. Familiarity with the situation did not seem to provide for learning the lack of danger in moving onto the glass on the cliff side.

Rats, which use their vibrissae (whiskers) as well as vision, seemed able to traverse the glass on the cliff side so long as their vibrissae could make contact with the glass. When the platform board was raised enough to prevent their vibrissae from touching the glass, they shunned the cliff. Almost all the trials involved descending from the board on the "safe" side. Putting the checkerboard pattern 10 inches below the board on both sides was enough to hold the rats on the board.

The subjects showing the poorest behavior were the turtles. On the cliff side reflections from the glass simulate somewhat the appearance of

water but failed to cause the aquatic turtles to choose the cliff side. About three-quarters of the turtles crawled off the board on the "land" side.

Walk, Gibson, and Tighe (1957) compared "dark-reared" and "light-reared" 90-day-old rats on the visual cliff. The dark-reared animals were placed on the visual cliff apparatus. The experimenters found that the dark-reared and light-reared litter mates behaved alike.

DeHardt and Whitney (1964) were interested in depth discrimination as it pertained to the standard visual cliff. The essential feature of most if not of all visual cliffs is the plate of glass through which can be seen the underlying surfaces on the two sides of the platform. On one side the visual surface is either the design glued to the undersurface of the glass itself or a surface very slightly below it, making this the "shallow" side. The other side, the "deep" side, is generally the floor of the room, on which the apparatus is placed. DeHardt and Whitney were concerned about the fact that the total visual field on the deep side is essentially more extensive than the field on the shallow side. They wondered whether some of the additional features of the total field might not be an effective component in providing for the animal's depth discrimination. The general purpose of their investigation was to determine the effect of enclosing the deep side of the cliff, thus eliminating features other than the texture pattern, and making that side visually less "open." It is known that rats tend to avoid open areas.

Two experiments were performed. Experiment I used open and enclosed cliffs. Experiment II attempted to determine whether "texture density" is a sufficient basis for depth discrimination in rats. Walk and Gibson (1960) had stated that their rats chose to walk on a 3/4-inch checkered pattern rather than on a 1/4-inch pattern, where no differences in the actual depths of the two sides were involved. This was interpreted as being due to the rats' perceiving the smaller checks as a surface farther below them than the surface with the larger checks. DeHardt and Whitney supposed that "texture density" alone was not sufficient to explain the rats' choice. Experiment II was meant to test this.

In Experiment II only the enclosed cliff was used. In one part of the experiment 3-inch and 1-inch squares were used on the opposite sides of the cliff with the actual surfaces on both sides being only 3/4 of an inch below the glass. In the other part of the experiment, 1-inch and 1/4-inch checkered gingham cloth was used in the same way.

In all parts of the experiment, DeHardt and Whitney in their final tally counted only the responses that were made following what appeared to be a "look" at both sides of the cliff, although they kept track of responses that were made without this look as well as the cases in which no response was made.

The open and closed cliffs provided very unlike results. On the closed cliff, there was no significant difference in the number of choice responses

made to the two sides. On the open cliff, almost all the animals chose the shallow side. From the results, it was thought that by enclosing the deep side of the cliff the factors sufficient for depth discrimination had been eliminated.

A third experiment was performed. Twenty-two naive adult rats were conditioned to go to food on the shallow side and some on the deep side of the enclosed cliff. The side to which the animal was to go was determined randomly. Twenty-one of the twenty-two readily learned the task. The conclusion was made that, whereas rats can discriminate between the two sides of the cliff, the discrimination does not represent a depth discrimination of the sort that would explain the preferential choices in Experiment I. DeHardt and Whitney finally concluded that they had not found a basis for denying depth discrimination, but at the same time they believed that the cliff performance did not demonstrate its operation here.

Reafference in the development of visually guided behavior

In the studies about to be described, attention to muscle participation in visual perception was focal.

Held and Hein (1963) set about to answer the question of whether movement-produced stimulation functions in the initial development of visually guided behavior as it has been shown to function in adaptation to rearranged visual situations. Riesen's work (1960) indicates that this principle operates in original learning, but he suggested that sensory-sensory associations rather than sensory-motor associations were the crucial factor.

Held and Hein used ten pairs of kittens, each pair from a different litter. The apparatus for equating motion and resultant feedback for the active and the passive member of each pair of kittens was a large drum with vertical stripes (Fig. 2.3). The passive subject was placed in a gondola and kept there by a body clamp and neck yoke. The bar from which the gondola was suspended was balanced by a counterweight. The active subject was placed in a body clamp and neck yoke but this did not preclude the kitten's being able to walk on the floor of the drum. The path followed by the active kitten was thus followed by the passive one since the two were on opposite ends of the bar pivoted in the middle. The active kitten was able to move in either direction around the drum. When the direction was reversed, the reversal was transmitted to the gondola of the passive kitten by a chain device. This turned the gondola in the opposite direction from which it had been pointed, so that the kitten in the gondola was always facing in the direction it was being propelled.

The floor of the drum was textured masonite and served as additional visual stimulus material. For both animals the sight of their paws was excluded by extension in the neck yokes. Three types of test were used on

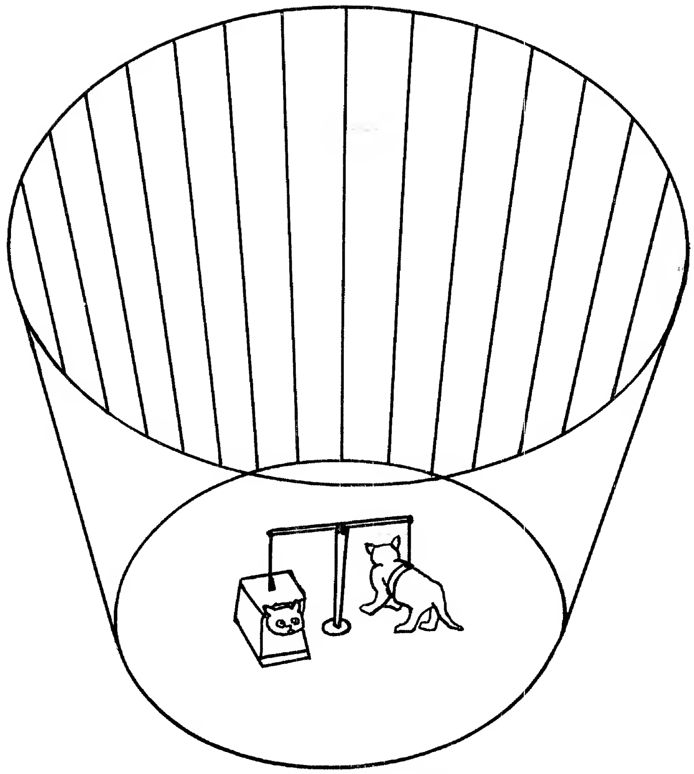


Fig. 2.3. Held and Hein's drum apparatus for studying differences between active and passive visual exposure. (R. Held & A. Hein. Movement-produced stimulation in the development of visually guided behavior. *J. comp. physiol. Psychol.*, 1963, **56**, 872–876, Fig. 1.)

the animals following their time in the drum: (1) visually guided paw placement, (2) avoidance of a visual cliff, and (3) blinking to an approaching visual target.

The ten pairs of kittens were divided into two groups, A and B. The eight pairs in group A were reared in unilluminated quarters from birth until one of each pair became big enough to move its mate in the gondola. This age varied from 8 to 12 weeks. The practice period was 3 hours daily. In group B, the two pairs of kittens were treated somewhat differently but we need not describe this here.

It took some time for the active kitten in each pair to develop the visually guided paw placement response. By the time it had been developed in each active member, the passive member still failed to display the response. Even among the active kittens, the livelier ones developed the paw placement reaction soonest. The blink response developed along with

the paw placement response. The passive member of each kitten pair showed no outward evidence of discriminating the shallow side of the visual cliff.

The results of the investigation were entirely consistent with the supposition that self-produced movement with its concomitant visual feedback is required for the development of visually guided behavior.

Held and Bauer (1967) tested monkeys with regard to the same matter but in a different way. The monkeys were raised from birth in an apparatus that precluded their seeing their body parts. At the age of 35 days, one hand was exposed to view. The animal's visual fixation of the hand was persistent. The animal's initial visually guided reaching was quite ineffective but it improved during a 10-hour test period. In contrast, reaching with the other hand, which had not yet been seen, improved very little.

Primates

Primates seem to have difficulty developing perceptual facilities if development has been precluded during earlier life. This is attested to by the difficulties in visual performance following experimental darkness during infancy and by the difficulties encountered by humans when they have been victims of cataracts obstructing vision during the first few years of life. Both apes and humans are unable to perceive the meaning of the visual targets for a long time after they have been first rendered able to receive images on their retinas. While the difficulties may be described as features of the learning process, they are nevertheless descriptive of the state of perception under the conditions mentioned.

HUMAN ONTOGENETIC DEVELOPMENT

Human fetuses

The very earliest response to tactile stimulation is manifested in fetal life, the prebirth stage, of the individual, where such factors as temporal and spatial summation are evidenced. Repeated contacts of the fetus with a light hair are effective when a single contact is not. Contact with a brush containing a number of hairs is effective, when a single hair is not. Different responses are elicited in premature infants by grading impingements, or contacts, from weak to strong. Response is quite consistent from trial to trial and depends upon the zone contacted.

The fetus responds to warmth and cold, according to Preyer (1885) and Blanton (1917). Pratt, Nelson, and Sun (1930) found that the responses of newborn infants to "stimuli" that are colder than the body are more intense than responses to "stimuli" that are warmer than the body.

Cutaneous pain does not seem to be evokable in the fetus, as is attested by the relative weakness of overt reaction to impingements that cause destruction to skin and underlying tissue. Sometimes no overt response is elicited in premature infants during the first day, even when the impinge-

ments draw blood. Carmichael (1934) remarks in this connection, that less response is evoked in fetal guinea pigs by such impingements than by contact with a fine hair at the same point.

Taste receptors have been reported to be more widely distributed in the early fetus than in the adult. It has been found that the human infant at birth can distinguish between salt, sour, and bitter as against sweet.

There is some evidence that the auditory receptors of the human fetus can be stimulated under some conditions. For example, it has been reported that a distinct response of a child in the womb was elicited again and again by striking the bathtub in which the mother was seated. A wide range of tones was used to stimulate the child in utero by certain other investigators.

Response indicating distinction between light and dark can be elicited in a 7-month (that is, premature) infant. This is, of course, despite the fact that the optic nerve and other visual structures are not fully mature, even at 9 months, the normal time of birth.

Human subjects lacking visual form stimulation from birth

Understanding perceptual development and change has depended upon a number of unique approaches. For example, there is the determination of the characteristics of vision in individuals who from birth were unable to see form on account of cataracts, until later operated upon for their removal. Senden's book reporting such cases first appeared in German in 1932; Révész (1950) examined Senden and eliminated the totally unreliable cases, leaving about twenty-two extending from the years 1810 to 1928. Even these cases leave much to be desired but they did seem to yield to certain generalizations, which Révész stated essentially as follows. Size differences between visual objects could be correctly perceived immediately after operation, although there was no clear demonstration of immediate visual recognition of forms. This failure referred even to items that had been familiar tactual objects before operation. No general conclusion in regard to seeing movement seemed to be possible from the evidence. It was also concluded that two- and three-dimensional objects could not be visually distinguished.

Some who have reviewed the evidence have concluded that, even several weeks following the operation, certain simple visual forms such as triangles and circles could not be recognized for what they were.

Human infants: Fantz

Fantz (1961) studied human infants by using the activity of the eyes. He supposed that if the subject persistently fixates some forms and not others, it must be able to perceive differences between them. The subjects lay on their backs in a crib inside a special chamber of uniform reflectance

and illumination. To the ceiling were attached pairs of items (targets) that were exposed to the subject alternately to the right and to the left for certain test periods. Through a peep-hole in the ceiling the mirrored images were seen on the subject's eyes. It was therefore known when the subject was fixating, or looking at, the item by observing where the images fell on the eyes. If the image fell on the pupil, it was supposed that the item was forming a retinal image and was being looked at by the infant. The time spent fixating each item and the time spent looking elsewhere was recorded.

The supposition was, of course, that the visual system of human new-born infants is poorly developed, so that the ability to distinguish complex patterns might not be expected. The first targets used on human infants were equal-sized areas, such as bull's eyes, horizontal strips, checkerboards and two sizes of plain square, a cross and a circle, and two triangles. Thirty infants aged one to 15 weeks were tested at weekly intervals.

Later, black and white stripes and uniform gray areas were compared. The two targets were equated for overall luminance. After it was found that the infants fixated the striped targets more than the plain ones, quantification was effected by using a series of striped targets containing progressively narrower strips. It was found that with increasing age the subjects could distinguish targets with narrower and narrower stripes. The infants could distinguish stripes $\frac{1}{64}$ of an inch wide at a viewing distance of 10 inches before reaching 6 months of age. This involves a visual angle of 5 minutes of arc as compared to the normal adult's one minute. At the age of about one month, the visual angle involved was about one degree or 60 minutes. This poor showing at this age was a long way from what we know as adult vision, but it still represents the capacity to distinguish form.

Later, Fantz (1964) tested forty-nine infants ranging from 4 days to 6 months in age. They were shown three flat targets the size and shape of a head. One consisted of a stylized black face on a pink background. In the second the features were scrambled, and in the third target the pattern consisted of a solid black area equal to the combined area of the features in either of the other two. In all cases, the features were large enough to cover visual angles larger than those known to be used by infants in the earlier experiments. The results in general were that the "real" face was fixated most, the scrambled face next, and the other target least. The results were interpreted as showing that in human infants there is a primitive significance in form perception as in chicks.

A third step was made in testing the infants, using a solid sphere and a flat circle, the former being more "interesting" to infants even in the one-month to 6-month range of age.

Human infants: Bower

Another approach to determining the presence of form and space perception was taken by Bower (1965), who used an operant conditioning

procedure. The response utilized was a turning of the head. The infant lay with its head between two pads and, by as little as a ½-inch turn to the right or left, a microswitch was activated that operated a recorder. In such a set-up, the infant's effort was scant, and even a 2-week-old child could provide four-hundred responses with no noticeable "fatigue."

One of the experiments was meant to determine whether infants can perceive distance and manifest "size constancy" in their behavior. The reinforcement used in the conditioning procedure was provided by the ordinary game of "peek-a-boo." Each subject was trained to respond only in the presence of a white 12-inch cube located one meter from the eye. We shall call this situation 1, or S_1 (Fig. 2.4). Following one hour of this, three

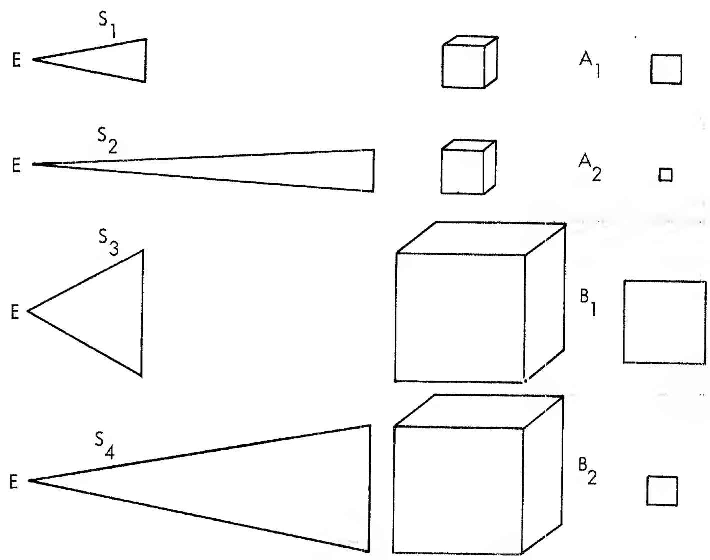


Fig. 2.4. Target arrangements used by Bower. S_1, S_2, S_3, and S_4 represent the various situations. The visual angles dependent upon cube distance are shown subtended, and the righthand column of squares indicates the resultant relative sizes of the visual images in the respective situations.

new situations were introduced. For S_2 the original 12-inch cube was placed 3 meters away. For S_3 a 36-inch cube was placed at a distance of one meter, and for S_4 the 36-inch cube was moved to a distance of 3 meters. All four situations were alternated in a counter-balanced sequence, and the number of responses evoked by each were noted.

S_1, the original conditioned situation, would be expected to evoke the highest number of responses. If the infants were affected by the cube distance, and thus perceived distance, but did not respond on the basis of

"size constancy," situation S_4 should seem more like S_1 than would S_2. The cubes in S_2 and S_4 were at the same distance, but S_4 would produce a retinal image of the same area as S_1, whereas S_2 would produce an image of only one-ninth the area. Were the infants able to discriminate distance but not to respond on the basis of "size constancy," S_3 would produce more responses than S_2, since S_3 involves the same distances as S_1 whereas S_2 does not.

If, however, the infants were able to discriminate distance and were to exhibit "size constancy," S_1 and S_3 should have evoked about the same number of responses, since they differed from S_1 in one or the other of the major factors. S_2 differed from S_1 in distance, and S_3 differed in size; S_4 should have produced the fewest responses, since it differed from S_1 in both size and distance.

The empiricist predictions, according to Bower, would have been as follows: S_4 would elicit at least as many responses as S_3. S_3 would elicit more responses than S_2. Not taking distance factors into account, S_4 should be more effective than S_3. Nativistic predictions would have been the opposite—that is, S_2 would be more effective than S_3, and there would be more responses to S_3 than to S_4.

The experimental results were as follows: S_1 evoked ninety-eight responses, S_2 fifty-eight responses, S_3 fifty-four, and S_4 twenty-two. Bower concluded that the infants did respond on the basis of actual cube size and actual cube distance but not on the size of the retinal image.

The investigation was of course not complete at this point. Several factors, such as binocular parallax and motion parallax, had not been prevented from operating. Accordingly, a new group of infants was tested under new conditions: the infants wore a patch over one eye so that binocular parallax could not operate; all that could function was motion parallax and pictorial factors, or "cues." A second group of infants viewed lantern slides copious in pictorial factors but with no basis for either binocular or motion parallax. A third group wore stereoscopic goggles designed especially for the experiment; the stereo-grams were of the cube situations; binocular parallax and pictorial factors were present, but motion parallax was precluded.

The results showed that the "monocular" infants behaved just as the unrestricted infants did. In this experiment, S_1 produced 101 responses; S_2 sixty responses, and S_3 fifty-three responses, while S_4 elicited but twenty-two responses. The group that looked at the slides did very differently. Ninety-four responses were made to S_1, 52 to S_2, 44 to S_3, and 96 to S_4. Bower concluded from this that the infants responded exclusively to the projected retinal image sizes. The pictorial factors in the slides were seemingly ineffective; otherwise, S_4 could not have been nearly as effective as it was. The behavior of the stereoscope group was like none of the others. Some "size constancy" was interpreted from their behavior but

not as much as in the original group, or "monocular," group. Here S_1 evoked ninety-four responses, S_2 forty-four, S_3 forty, and S_4 thirty-two.

Bower performed another investigation with young infants, which involved the use of targets varying in their orientation, or slant, with reference to the viewer and targets differing in shape. The conditioned target in situation one, or S_1, was a wooden rectangle approximately 10 by 20 inches located 2 meters from the eye and turned 45° from the frontal plane. The target formed a trapezoidal image on the retina. S_2 was the same rectangle at right angles to the line of regard (in the frontal plane). S_3 was a trapezoid placed in the frontal plane. This trapezoid formed the same trapezoidal retinal image as the rectangular target in S_1. S_4 was the same trapezoid turned in the 45° position to form a rectangular image.

Bower supposed that if the subjects demonstrated "shape constancy," S_2 would elicit more responses than S_4; S_4 would be about the same as S_3. On the other hand, if retinal image shape were the prime determining factor, S_3 would elicit more responses than S_4 or S_2.

In the experiment, the conditioned situation S_1 elicited an average of 51 responses, S_2 45 responses, S_3 an average of only 28.5 responses, and S_4 26 responses. Thus there was no doubt that the infants, between 50 and 60 days old, responded in accord with the actual shape of the cubes and not the retinal image shape. There was no statistical difference in the number of responses to S_1 and S_2. "Shape constancy" was demonstrated, and the different orientations of the targets made no discriminatory difference.

This puzzled Bower, and so he made three additional experiments. In the first, the targets varied in image shape and orientation, while target shape remained constant. In the second, target shape varied and so did retinal image shape, while target orientation was constant. In the third, only orientation varied, while target shape and image shape remained fixed.

In the first experiment, the infants responded as though the three test situations were the same as the conditioned one—that is, $S_1 = S_2 = S_3 = S_4$. In the second and third experiments, the infants showed that variations in target shape, image shape, and orientation can be discriminated. Bower concluded that the infants in the first experiment reacted to target shape (since it was the same in S_1, S_2, S_3, and S_4) as a more salient factor than the target orientations or the retinal image shapes. Bower made a powerful point here, by emphasizing that both the early empiricists and the nativists were wrong in supposing that the perception of simple factors precedes the perception of complex variables.

Additional evidence for form discrimination in the newborn

Hershenson, Munsinger, and Kessen (1965) presented neonate humans with pairs of visual targets containing geometric forms differing in the

number of turns or angles they contained. Preference for particular forms was interpreted from the number of times fixated. The procedure was somewhat like that of Fantz. Infrared photography was used to record eye positions and fixations. The targets were above the reclining infants at a distance of about 46 centimeters and were 15° to each side of the point viewed when the subject looked straight up. The targets contained either five, ten, or twenty turns. The infants fixated on the ten-turn targets the most and on the five-turn targets the least.

The same sort of an investigation had previously been conducted on elementary school children and on adults, and no distinction between the two groups was disclosed. The targets contained from three to forty independent turns, and targets containing ten turns were fixated the most.

It was concluded that the neonates could perceive form and that somewhat the same factors operated against the appreciating of extreme complexity with the older subjects as with the neonates.

Human infants: visual cliff

The use of the visual cliff was described earlier in connection with small animals. Walk and Gibson (1960) showed that binocular human infants can discriminate depth as soon as they can crawl. These experimenters were concerned with whether monocular infants can make the depth discrimination also required in the cliff behavior.

In the visual cliff set-up, tactual, auditory, and olfactory factors or "cues" are equalized by the glass that is the top surface of the set-up. Enclosing the apparatus precludes the use of familiar objects—for example, the feet and legs of the mother cannot be used as cues for distance.

Ninety-six percent of the many binocular infants tested crawled to the mother over the shallow side. Some of the infants could be coaxed to crawl over the deep side with certain enticements but not with others. It was found that the infants in the 7- to 9-month age range were more likely to cross the deep side than were those in the 10- to 13-month range. The results thus showed depth discrimination at all ages tested but a certain variability in behavior when less definite patterns were used in the cliff apparatus.

The infant used to test monocular vision was a child 10.5 months old. Cancer had necessitated the removal of its right eye at the age of 5.5 months. Prior to that, the eye had been blind. The monocular infant was placed in the usual starting position, and in the first trial it was called from the shallow side and crawled to the mother. In the second trial, the mother called from the deep side but the infant crawled off across the shallow side after backing away from the deep side. On subsequent trials, the infant refused to crawl off across the deep side, regardless of the coaxing from the mother stationed on the deep side. Behavior was consistent with that

of binocular infants and the behavior of most animals placed on the apparatus.

Children

So much for some of the very beginnings of immediate discriminatory response of the human individual to his surrounds. We now turn to some of the individual's developments during later stages. The development of perception as a function of age in the human subject has best been exemplified by the work of Gesell and his colleagues over the past several decades. They particularly studied visual perception in the growing child from birth through his early years.

Gesell, Ilg, and Bullis (1949) gave attention to the perceptual growth of the child by studying five aspects of his behavior. The first of these was eye-hand coordination. The neonate was observed to begin at once to deploy his eyes, to move and stop them, which signifies a beginning active endeavor to adapt to the circumstances around him. This beginning behavior, however, is very crude, incomplete, and ineffective. Pursuit movements of a sort and the ability to fixate come in the first 4 weeks. By 12 weeks he can follow an object 180 degrees with blinking, jerky movements. By 16 weeks he can retain a toy in his hand, with occasional observation of it. By 24 weeks he discriminates between strangers. By 36 weeks he feeds himself a cracker. By 48 weeks he plays alternately with several toys. By 52 weeks he offers toys to another person and enjoys a give-and-take performance. Although ordinarily thought of in terms other than of perception, all this is a sense-guided type of behavior.

By 2 years the child has freed his eyes from his hands and may inspect objects with his eyes alone. At 2½ years "an object in another child's hand may be seen without regard for the child" himself. At 3½ years the child moves his head close to a magazine page to identify something or may move away and withdraw his head to a greater distance. By 4 years a free and fluid eye-hand relationship is achieved.

This and much more may be said about the typical child, indicating the development of a relation between himself and his environment that involves several achievements: the control of his ocular manipulative mechanisms, the manipulation of his geometrical relations to his surrounds, and the utilization of his surrounds to achieve purpose. During this time, the very evident early limitations in behavior can be seen to slip away, stage by stage, freeing him for a more fluid relationship with his surrounds. Perception plays a predominant role at all stages.

Intersensory comparison tasks

One of the methods of evolution has been the development of efficacy in behavior by increased and varied interaction between a limited number

of sense modalities rather than a proliferation in the number of sense modalities. As far as the individual is concerned, this can be observed in the early years of life. Examining this is one form of the study of perceptual learning, of which the work of Birch and his colleagues is an instance. Examples of the lack of intersensory cooperation in the animal scale help to make clear what is meant.

Birch and Lefford (1963) cite Abbot's work of many years ago in which he showed that the frog could not modify a visually controlled response through effects obtained from the pain modality. For example, a frog allowed to strike at a live fly impaled on a rod surrounded by a ring of sharp stakes would continue to try to obtain the fly by thrusting out its tongue even though every thrust resulted in impaling its tongue on the stakes; typically, the frog continues until its tongue is torn to shreds. On the other hand, in the same species the visual response is modifiable by effects received through another sensory channel, that of the sense of taste. This was shown by another experimenter, who demonstrated that the tongue-striking procedure was modified by the taste of a "bitter" caterpillar. Birch and Lefford confirmed this by showing that a target coated with quinine will inhibit the striking reaction. These experiments thus show that visually guided behavior in the frog is not modified by tactual stimulation but is modified by gustatory stimulation. In mammals there seems to be a further advance by way of the more widespread interaction between the senses.

The study of intersensory development made by Birch and Lefford on children consisted in comparisons of the interactions between haptic, kinesthetic, and visual modes of response. By haptic was meant the "complex sensory input obtained by active manual exploration of a test object." Performance of this sort involved tactile, kinesthetic, and surface-movement sensations obtained in manipulating an item such as a block. This was an active performance. What the experimenters meant by kinesthetic sense was the sensory input provided by passive movement of the arm, wrist, elbow, and shoulders.

They studied what they called intersensory equivalence. An item such as a block that was presented visually as an outline form on paper was used as a standard, and the experimenters compared the same and different forms presented haptically as wooden blocks or kinesthetically as grooves traced while the child's hand held a stylus and was moved in the groove by the experimenter. Thus, three comparisons were used: (1) visual-haptic, (2) visual-kinesthetic, and (3) haptic-kinesthetic. Stimuli were paired; the first member of the pair was presented to one sense, the second to the other sense or group of senses. Eight different stimulus forms were used: triangle, square, cross, star, half-circle, circle, diamond, and hexagon.

The subjects were children of both sexes ranging from 5 to 11 years of age. Two kinds of error were determined for each age group. The first were errors of *nonequivalence*—that is, errors made by failing to recognize

equivalent forms presented in the intersensory comparisons. The second were errors of *equivalence*, the failures to recognize different forms presented in the intersensory comparisons.

We shall first deal with the errors of nonequivalence. The 5-year-olds averaged 2.3 errors in the visual-haptic comparisons, the number of errors in individual cases ranging from zero to eleven. The 8-year-olds averaged 0.4 errors with a range of zero to 2.

In the visual-kinesthetic comparisons, the 5-year-olds made an average of 7.9, with a range of one to 14 errors. The 11-year-olds made an average of 1.8 errors with a range of zero to 7.

The average number of errors for the haptic-kinesthetic comparisons at 5 years was 7.9. The range was one to 14 errors. The 11-year-olds averaged 1.7 errors with a range of zero to 6.

The following resulted from the study of errors of equivalence. In the visual-haptic comparisons, the 5-year-olds averaged 2.9 errors with a spread of zero to eleven. The 11-year-olds averaged 0.7 errors with a spread of zero to 3.

In the visual-kinesthetic comparisons, the 5-year-old average was 5.7 errors, with a range of one to 27. The 11-year-olds averaged 1.4 errors, with a range of zero to 7 errors.

In the haptic-kinesthetic comparisons the average number of errors for the 5-year-olds was 4.6, with a range of zero to 15. For the 11-year-olds the average dropped to 0.9 with a range of zero to 3 errors.

In all cases, the curves depicting errors for the various ages had reached an asymptote by the eleventh year.

It was concluded that: (1) the ability to make intersensory comparisons improved with age; the growth curve was a typical logarithmic curve. This tallies with the idea that intersensory functioning is an example of the general law of growth. (2) The fewest errors were made in the visual-haptic comparisons. (3) In errors of nonequivalence, the visual-kinesthetic and haptic-kinesthetic were about alike in number. In the errors of equivalence, the haptic-kinesthetic comparisons seemed to be less difficult than the visual kinesthetic. (4) Individual differences in performance tended to decrease with age. (5) Comparisons of identical forms were generally more difficult to make than comparisons of nonidentical forms. (6) Performances with preferred and nonpreferred hands were not significantly different.

Birch and Belmont (1964a) compared brain-damaged children with normals in their ability in *intrasensory* and *intersensory* functioning. They found that the two groups were not significantly different in intrasensory functioning but that they did differ in intersensory functioning. The tests were on horizontality, verticality, and object distance in an unilluminated room as against a lighted room. The two groups differed in their behavior in the unilluminated room.

Birch and Belmont (1964b) compared retarded readers with normals

in auditory-visual integration and concluded that the retarded readers were less able to succeed in auditory-visual equivalence comparisons than the normal readers.

Still supposing that complex adaptive functions in childhood are dependent upon the development of interactions between separate sensory systems, Birch and Belmont (1965) studied auditory-visual integration in brain-damaged and normal children. The subjects were to identify a spatial visual-dot pattern that was perceived to be the same as the temporal pattern of taps they were presented with. The auditory stimuli, the taps, were separated from each other in the pattern by either a half-second or one second. The subjects were 88 brain-damaged children and 220 normals. The range in age of the brain-damaged was from 5 years 7 months to 20 years 10 months. The auditory-visual integrative capacities of the brain-damaged children were found to be significantly below the normals of the same age. The experimenters concluded that the perceptual and perceptual-motor difficulties found in the brain-damaged subjects might stem from disturbed intersensory integration.

Tactual localization and object size

Another line of investigation on the development of perception is illustrated in the work of Renshaw and his colleagues on tactual localization, which involved comparisons between blind and sighted children and adults. These studies are mentioned later in Chapter Twelve. It was found that sighted children were superior to sighted adults in tactual localization. This was interpreted as due to adults shifting to a dependence upon vision in localization. Renshaw and Wherry (1931) found that tactual-kinesthetic localization is superior to visual localization in children from the eighth to the twelfth year, where the difference between the two disappears. During puberty, localization by both means increases and then between the thirteenth and fifteenth years visual localization becomes superior and increases for some years as age increases.

The same shift from prepubertal to postpubertal behavior was interpretable when the studies of Bartley (1953) and Bartley, Clifford, and Calvin (1955) are taken together. Subjects below the age of 10 years performed essentially differently from a college-age group when tactual information was used to determine object size. The behavior of the college-age group showed the influence of the visual sense modality (see Chapter Twelve).

Without a doubt, it seems that various types of performance dependent upon sensory functioning are not equally difficult and that normally difficulty lessens during childhood development. The performances can be analyzed into those dependent upon mainly a single modality and those dependent vary definitely upon the participation of several forms of modal-

ity information or, as Birch and his colleagues put it, upon intersensory organization. This organization shows a traceable development up to about puberty. Various subnormal groups such as the brain-damaged children and the retarded readers show their deficits particularly in the tasks involving intersensory organization.

Intersensory development shows itself not only in tests such as those used by Birch and his colleagues but in tests of tactual localization and the use of tactual information. Below puberty, tactual information is utilized more nearly without help from the visual mechanism, but from then on visual influences begin to participate even when the information received is only tactual.

INTERPRETATION OF THE DEVELOPMENT OF PERCEPTION

Another category in the study of perception development has to do primarily with development of the perception of specific targets. This may be studied as the reaction to a given stimulus as a function of repetition.

There are those who are concerned with the problem of whether the perception of simple geometric figures is learned and, if learned, what there is about such perceptions that is learned and how this learning takes place. Hebb deals with this general problem in his book *The Organization of Behavior* (1949). He believes that "simple" perceptions are complex: that the development of perceptions depends partly upon motor activity and that their seeming simplicity is only the end result of an extended learning process. To assert that perception is a product of previous encounters and the responses to them is not to indicate any new belief. To assert that perception depends upon motor activity is pretty much to state the belief that perception is a product of learning. Hebb's contribution is a formulation of how learning is accomplished and how it applies even to very simple forms, not only to the geometrically complex. Before stating his views, Hebb brings up the dilemma of whether perception is dependent upon the activation of specific cells in the nervous system or upon a pattern of cells whose location in the aggregate is not fixed. He points out that Lashley, on the one hand, and Gestalt theorists, on the other, have held the second view, and he opposes the Gestalt view in this matter. Hebb proposes that a specific perception depends upon the activity of a specified group of cells somewhere in the central nervous system. The Gestalt theorists assert that perception of a square or a circle, for example, is given directly as a unique whole and is achieved through neither a learning process nor any previous recognition of the component parts of the figure.

Hebb sets out to show that simple figures are not perceived as unique wholes and that perception of a square as a square depends upon a sequence of previous excitants from the components of the geometric

target. To make a start somewhere, he begins with a form of innate reaction that he calls reaction to *primitive unity*, really is the experience of figure-ground relations as first pictured by Rubin (1921).

The figure-ground perception is a segregation of the visual field into two portions, and it is thought to be a direct and inherent result of the pattern of sensory impingement and the inherited features of the nervous system upon which the impingement occurs. Thus this two-part structure is what is seen by any normal person and even by the congenitally blind, who finally view their surrounds for the first time after years of blindness from cataracts. Figure-ground perception is also given some credence in the behavior of rats raised in darkness and then put into an illuminated environment for the first time. This much Hebb credits as being independent of prior experience and thus not dependent upon integration of even more simple perceptions. He would allow the possibility that certain groupings or an ill-defined patch of color can be perceived as a unit and distinguished from its surroundings. Here we seem to be talking about sensorially determined relations that are responded to as such. But Hebb calls attention to nonsensory figure-ground organizations, which involve boundaries of figures not determined by gradients of luminosity of the visual sensory factors. He points out that the nonsensory figure emerges whenever the observer responds to a limited portion of a homogeneous field, as when one looks at "the corner of the room" or "the middle part" of a suspended rope. In each one, the part in question is perceived to have an identity distinct from the rest. This identity is not sensorially determined by geometric boundaries or other such stimulus features.

Hebb interprets the findings relative to the congenitally blind person's early visual perceptions as indicating that they are almost completely lacking in what he calls identity. Cases are reported in which such individuals were not always able to distinguish between spheres and cubes. Color, on the other hand, seemed to dominate the perceptions of such persons and would thus seem to be quite primitive. One of the outstanding cases was that in which an egg, a cube of sugar, and a potato were repeatedly shown to the subject until he could name them correctly. The mere placing of them in colored light negated their recognition. Likewise, context had a great deal to do with recognition, as in the case of the subject recognizing the cube of sugar when it was in the examiner's hand but not when suspended by a thread against a different background.

As an example of a case of learning to perceive a simple figure as such, Hebb uses the case of perceiving a triangle as different from some other figure. He pictures the case of perceptual acquisition as following a course from dominance of color, through an interim of separate attentions to the various portions of the target, to a final but gradually achieved identification of the whole target as a whole. Thus there is a progress from a serial

apprehension of portions of it to the final, simultaneous apprehension of the whole. The example is given of a patient taught to discriminate between a square and a triangle. At the end of 13 days, he had accomplished little, and to make the discrimination at all he had to count the corners, one by one. According to our definition of perception, he could make no immediate reactional distinction between square and triangle. He only arrived at a *judgment*, after several sequential operations, each of which involved a perception of a corner. The perception of corner, whatever it was, was probably related to the previous tactual explorations he had had while still blind. It was said that by this time the examiner had a feeling that recognition was in the process of becoming automatic and that someday the patient would be able, at a mere glance, to distinguish between square and triangle. The suggestion was made that anyone seeing the patient then, for the first time, would simply take it for granted that the form of a simple target was something inherently given in the target or stimulus itself.

This example leads to Hebb's conclusion that eye movements are an inherent part of learning to see simple forms, for it is they that provide for shifts in inspecting the various parts of the targets. In other words, multiple fixations on various parts of simple targets are necessary for the achievement of the perception of form, as we know it in the adult.

Hebb is basically interested in the neurophysiological foundation for perception, and to accomplish the explanation of learning (learning to perceive) he makes certain postulates regarding nervous activity. The first of these is the process of *association;* that is, when any two cells or systems of cells are active again and again concurrently, they will tend to become linked in such a way that activity in one facilitates or induces activity in the other. A solid three-dimensional mass of brain tissue, for example, would become assembled in a functional way. This, he thinks, is in part dependent upon a principle announced some time ago by a noted physiologist, according to which adjacent cells are so interrelated with each other anatomically that nerve impulses feed back into the pathways along which they travel, by reason of branches that bend back upon themselves. This forms, within the system, a reverberating activity that does not cease the instant the assembly is acted upon from tissue adjacent to it. Various assemblies may gain temporal overlaps in activity this way and tend to become associated. The interrelational effects of various assemblies are such that after many influences upon each other they evolve into a superordinate assembly that may underlie the perception of the target as a whole. The sequence of interactions of the various component assemblies is called a *phase sequence.* A train of thought, as well as the sequence that has to do with the acquisition of a perception, is also taken as depending upon a phase sequence in the underlying nervous system. Actually, what Hebb describes as a phase

sequence includes not only the neural activities just outlined but also the motor accompaniments that are involved as the subject looks from corner to corner of the triangle during his encounters with it.

As was stated earlier in this section, the relation of perception and learning has been studied by a number of workers. Some learning theorists treat perception as response. That is what we have been doing, of course, in the way we have defined it. The main difference between the statements of learning theorists and this book is that this book does not identify perception with all response: The response must be an immediate discriminative one. Response taken generally, on the other hand, includes reactions that are called judgments. While judgments accrue from perceptions and may be fairly good indicators of what perception is like, they cannot be taken indiscriminately as interchangeable with perception.

CONCLUSIONS

The material in this chapter has demonstrated the changeableness of sensory response. It shows that what we consider as perception in the adult has come to be what it is through a long and many-sided development. This is one of the most significant things that can be said about this basic, immediate, discriminatory behavior that relates the individual to his surrounds. To discard the idea that sensory response can be cryptically disposed of by calling it stimulus-bound is to recognize a new possibility in its study. To recognize that perception is a true and useful expression of personality and, like its other expressions, follows discoverable laws is to invite its study for the solution of many problems in psychology approached heretofore only in other ways.

The study of discriminative behavior of subhuman species may well be seen as a demonstration not simply of the abstract thing called learning but also of the educability of the most basic forms of response. Much of what has been classified as sensory has been simply attributed to the peculiar differentiating ability of the sense organs. Change, when it has occurred, has been abstracted into a category by itself. It has been studied as *learning*, not as the development of perception. Seeing it as the development of perception might be quite helpful in gaining a better understanding of the whole animal kingdom.

The comparisons between human and subhuman reactions to given targets have led to information that helps bridge the gap between what we may deal with in terms of experience or consciousness and what we can deal with in other ways. The reactions of chickens to geometric forms (or "illusions") is a good case in point. Chickens, without showing any evidence whatsoever of being able to verbalize, react to presented geometric forms as humans do: they see the "illusion," the same discrepancy from metrical size. In this connection, the educability of the hen, although its original

ability manifests certain marked limitations, has been demonstrated, and this, too, shows how perception may develop.

The work of Gesell and his colleagues (1949) has demonstrated with book retinoscopy that the ebb and flow of understanding are manifested in the nonverbal expressions of perception, in the very reflexes of the eye. This comes out in a way hitherto undreamed of. This discovery has shown that intelligence is concretely expressed and measurable in a nonverbal body mechanism—a perceptual response itself—rather than by formal paper-and-pencil tests. Furthermore, the oculomotor expression can be dealt with without using formal instructions that none but an older child or an adult could comprehend. Furthermore, the same tests can be used to measure the growth of intelligence—or the growth of perception. This is a long step beyond having to deal with the organism through one or more intermediate mechanisms to tap the understanding of complex stimulus material.

SUMMARY

This chapter was divided into four parts: the introductory remarks, a comparative picture of response up and down the animal scale, the human ontogenetic development of response, and an interpretation of the development of perception.

The first part set forth a distinction between developmental studies and studies having to do with perceptual learning and change. It was indicated that the distinction would decide the contents of the chapter and of Chapter Fifteen.

The second part described certain experimental findings on animals, beginning with earthworms and ending with primates. The investigations included those in which animals were reared in restricted visual environments or in total visual deprivation and were later tested for their perceptual capacities. While most of the studies were behavioral, one or two studies were neurophysiological and anatomical. This part of the chapter also included studies using the visual cliff as a visual context. It included studies on the role of active movement (reafference) as a factor in visual development.

The third part of the chapter, dealing with ontogenetic development, had largely to do with the visual perception of infants at various stages. This included the work of Fantz, Bower, and Walk and Gibson, using the visual cliff, and Gesell and his colleagues. It also included the work of Birch and his colleagues on the nature of intersensory comparison tasks. The final studies pertained to the development of tactual localization and included the work of Renshaw and Bartley and their colleagues.

The final section of the chapter pertained to the interpretation of perceptual development as posited by Hebb.

2

THREE

Visual Acuity and the Retinal Image

Much vision in present-day living is vision at close range. The individual must be able to see small objects and to see closely adjacent objects and borders as separate. The same kind of visual ability, is required for seeing distant objects and separations between them, however, since the retinal images of such objects are also small. This ability is spoken of as *visual acuity*. Visual acuity is involved in limitless tasks from reading fine print to threading a needle to reading road signs at distances great enough so as to react effectively to them when driving fast-moving vehicles. Visual acuity is of prime concern in prescribing eye-glasses. The clinical concern with vision includes testing and measuring visual acuity to understanding the various body mechanisms that provide for it.

There are several factors in measuring visual acuity—namely, target size, separations between target elements, target distance, relative intensities (or luminosities) of target elements and target backgrounds, different parts of the spectrum involved in separate target elements, and the time during which the target acts. Thus, there are spatial, intensity, spectral, and temporal factors involved in the photic input to the eye. (One additional factor is of considerable importance—adaptation. The adaptive state of the eye will be dealt with in the following chapter.) Our first task is to deal with the spatial factors. Target size and distance can be combined in a measure called the *visual angle*, which specifies the amount of retinal separation between elements and is a factor in indicating the area covered by the retinal image.

The vertebrate eye is an optical-image-forming mechanism, creating an image or spatial pattern on the retina, or the inside of the back wall of

the eye-ball. The image bears certain orderly relations to the luminosity patterns in the target, although these are not strict one-to-one relations.

DEFINITION OF THE VISUAL ANGLE

The visual angle is the solid angle formed by the target at the eye. In designating the extent (size or area) of the retinal image, it might be expected that magnitudes in millimeters or square millimeters would be stated but they seldom are. A more useful and more easily obtained designation is used, the visual angle, which the image subtends.

From Fig. 3.1 it will be seen that two factors enter into the determination of visual angle. The one is target size; the other is the distance of the target from the eye. Specifying visual angle precludes the need of specifying the two factors of target size and target distance.

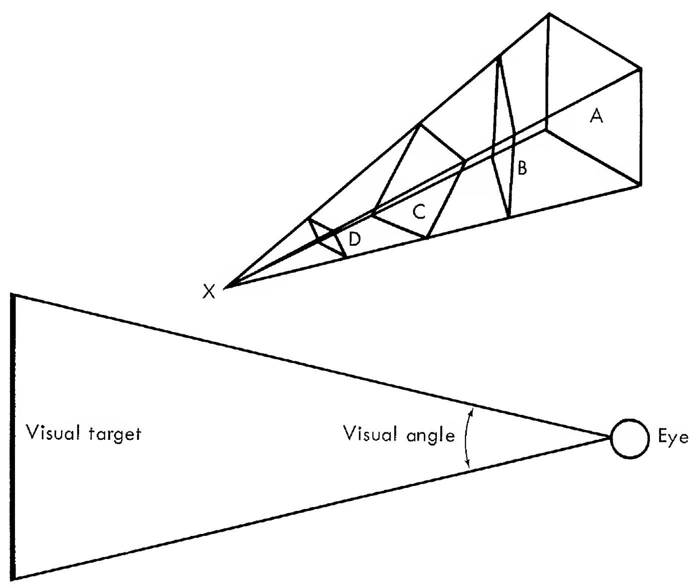


Fig. 3.1. The lower part of the diagram depicts the visual angle, which is the solid angle subtended at the eye by a target. A, B, C, and D in the upper part of the diagram are plane figures, each differing in size and position and all of which subtend the same visual angle at X.

This is not the only reason that visual angle is used. As a measure or unit, it relates to a great deal more that is known about the spatial features of the retina. For example, the two receptor populations are not homogeneously distributed throughout the retina. The fovea, which is the central area of the retina, has a diameter of from 1½ to 2°. Thus, by using targets with visual angles well below this subtense, one knows he is projecting an

image within the fovea, which is populated with cones alone. The distribution of both rods and cones over the remainder of the eye is pretty well known in terms of angular extents. The location of the optic disk, the retinal area devoid of receptors, is known and designated in angular terms. Likewise, the size and shape of the optic disk is given in angular terms. Visual acuity has long been designated in angular terms. It is designated as the reciprocal of one minute of arc, for instance.

Normal vision is such that target elements separated by one minute of arc can be seen as separate. Another way of saying this is that the visual system can *resolve* elements separated by one minute of arc. If more than this separation is required in any case, the visual acuity is substandard. If smaller angles are sufficient, visual acuity is better than normal. Thus, if one uses the reciprocal of the value found, based on one minute of arc, visual acuity is given a quantitative statement. The reciprocal of 2, being ½, would indicate that visual acuity is ½, or 0.5. Likewise, if only ½ minute of arc is required, visual acuity is the reciprocal of ½, or 2. Thus, the details of size and distance are not expressed but are only latent in stating visual acuity. This works only up to a certain point. Clinically, it has long been known that distance does count. Some people have good visual acuity for close targets and poor for distant ones. Other people are just the opposite. Thus, visual acuity is usually tested for two different and unlike distances, at about 16 inches and at 20 feet, representing near vision and far vision, respectively.

To find visual acuity in angular terms—that is, in minutes—one uses a trigonometric function, the *tangent*.[2] In Fig. 3.2 the tangent is A/B: One divides one half of the linear value of the target by the distance of the target from the eye. This provides a decimal value that can be used in consulting a trigonometric table, which will show the angle corresponding to the decimal value. For example, let us say that the overall target size is 2 inches and that the target distance from the eye is 50 inches. A = 1 and B = 50; thus, from A/B, or 1/50, the decimal is .02. The tangent of .02 is 1°9′. But since this is only one-half of the target dimension, the full dimension subtends 2°18′ of visual angle.

IMAGE FORMATION IN THE EYE

The human eye is several things; for one, it is an image-forming device, and the retina is a sensitive carpet on which the image can be spread. This image is the optical counterpart of a target and is produced by a lens or

[2] Trigonometric functions and tables giving their values are based on triangles in which one angle is a right angle. Dividing the overall target value, or the value of a target element, by two (using one half of the visual angle) provides a right-angled triangle, here triangle ABC. When its value is obtained, it can then be multiplied by two to represent the whole target or target element in question.

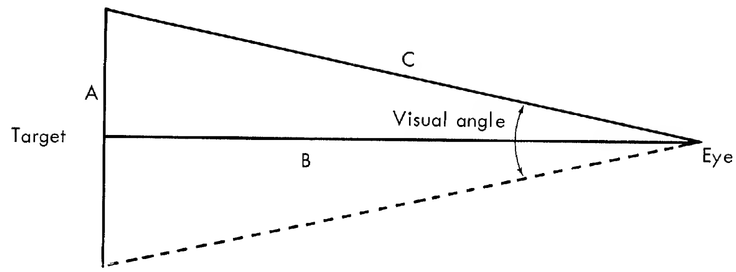


Fig. 3.2. Use of the tangent in specifying the visual angle subtended by a target. (The tangent is a geometrical function that involves right-angle triangles.) The dimensions used are one-half of the dimension of the target and the distance from the target to the eye, which together form the right angle AB of the triangle ABC. The tangent is A/B, one-half of the target dimension (A) divided by the distance from the target to the eye (B). This fraction put into decimal terms can be used to read from a trigonometric table the angular dimension of the angle BC. This value is one-half of the visual angle and is doubled to represent the full visual angle subtended by the target at the eye.

other optical system. In the eye the image-forming device, or lens, is adjustable by means of a muscle system that changes the lens's thickness and curvature. This process is called *accommodation.* A muscle system also changes the size of the aperture (or pupil) through which photic flux reaches the lens and retina. The two eyes of the human make the system a double one in which each component or eye operates in effective conjunction with the other where there is—as there usually is—appropriate regulation of pupil size, accommodation, and (convergence muscular positioning of the eyes) so as to point at a common target.

Visual acuity depends first of all on proper image formation, which depends upon the proper utilization of photic radiation as it passes through the various media (the transparent tissues) of the eye. The photic rays change direction in accordance with the optical density of each of the media and the curvature of the surfaces between them, so that upon leaving a medium the direction of the rays is not the same as it was when they were entering it. This is called *refraction,* which is stated in terms of an index. The indices of refraction of some of the media are:

cornea	1.376
aqueous and vitreous	1.336
crystalline lens, cortex	1.366
crystalline lens, nucleus	1.406

Changes in thickness and curvature of the crystalline lens provide variable refraction. The shape of the crystalline lens, and thus the image

formation of the eye, is controlled by the muscles that immediately surround the lens. Muscle activity is in turn controlled by neural innervation. When the eyes accommodate—that is, when the lenses thicken and change their curvature from their relaxed shape—the two eyes converge and the pupils constrict.

People who correct the refractive anomalies of vision have a vocabulary that is not familiar to people in general. The normal-sighted person is called an emmetrope and his condition is *emmetropia*. People with anomalous vision are called ametropes, the condition *ametropia*. The three major forms of ametropia are *myopia*, *hyperopia*, and *presbyopia*. Certain differences between emmetropic and ametropic eyes are illustrated in Fig. 3.3.

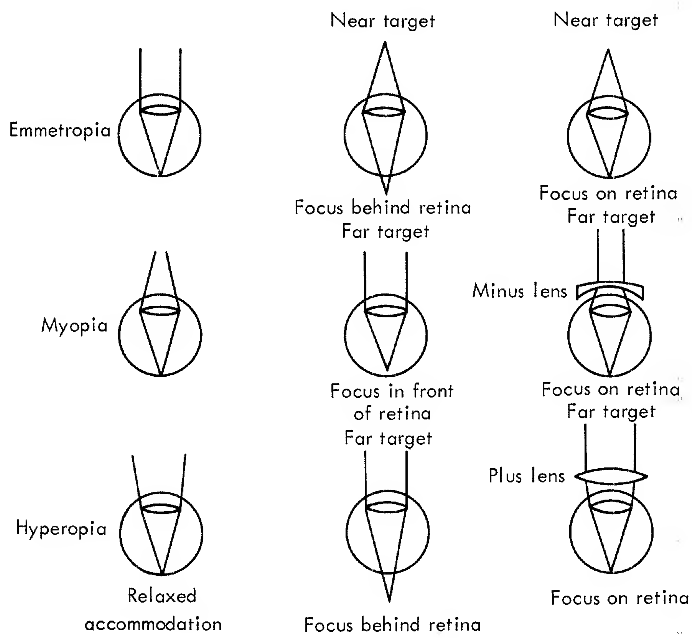


Fig. 3.3. Emmetropic, myopic, and hyperopic eyes focus incoming photic rays.

The first column indicates the direction of the rays needed for relaxed emmetropic, myopic, and hyperopic eyes to form an image on the retina. It will be noted that for the emmetropic eye, parallel rays are needed when accommodation is relaxed. For the myopic, rays must diverge from an image point. And for the hyperopic eye, rays converge as they reach the eye. In the first two cases, a distance from the eye is obtainable at which the relaxed, "resting" crystalline lens can focus a target. In the third case, no distance near or far is obtainable.

The second column shows a number of things. For the emmetropic

eye, near target points are focused behind the retina unless accommodation is utilized. For the myopic eye, parallel rays are brought to a focus at a point nearer than the retina. For the hyperopic eye, even parallel rays are brought to a focus behind the eye.

The third column shows that, for the emmetropic eye with positive accommodation, rays from points less than 20 feet away can be focused on the retina. For the myopic eye, a minus lens (one diverging the rays that pass through it) is needed to direct (that is, diverge) parallel rays to focus on the retina. For the hyperopic eye, a positive lens (one converging the rays that pass through it) is needed to bring parallel rays reaching the lens to a focus on the retina.

In all these conditions, it is of interest to know how far away a target can be and still be seen clearly (*far point*) and how close to the eye it can be and be seen clearly (*near point*). In the emmetrope, the far point is considered to be at infinity; the rays emerging from a point at infinity would be parallel at the eye. For clinical purposes a target at a finite distance of 20 feet or 6 meters can be considered equivalent to infinity; thus, the far point of an emmetrope can be called 20 feet. For a myope, the far point distance is somewhat less than that. For a hyperope, the far point is at some finite virtual distance behind the eye: only externally converging rays will come to a focus on the retina and there is no far point beyond the eye. For the hyperope no target point at any distance will be focused without accommodation. Positive accommodation (as from a plus lens) reduces the convergence needed and makes the eye at least able to focus parallel rays onto the retina. With such accommodation the hyperopic eye functions as the emmetropic eye does with relaxed accommodation.

The near point for clear vision is the shortest distance at which the fully accommodated eye will focus an image on the retina and thus provide for clear vision. This distance of course varies for the three eyes.

Presbyopia is the condition in older people in which the lens of the eye has lost some of its former elasticity and as a consequence accommodative adjustments are slower and reduced in amount. The far point comes nearer to the eye and the near point moves out.

Since human vision is a two-eye affair, visual acuity depends somewhat on the mechanisms that have to do with the proper directing of the two eyes toward a common fixation point. The posture of the two eyes always involves some degree of convergence. Convergence is largely a reflex process, and so is accommodation. These two reflexes work together and influence each other in a complex way, but according to rule.

Our interest is in how the eye with and without spectacles can utilize parallel, converging, and diverging rays for clear vision. From what we have said, we know that the emmetropic eye with relaxed accommodation can use parallel rays, the myopic eye can use diverging rays, and the hyperopic

eye can use converging rays. How does this directional utilization relate to targets at the distances confronted in everyday life?

VISUAL ACUITY TARGETS

Visual acuity targets are used in two different kinds of situations. They are used by clinicians in testing visual functions, and they are also used in the laboratory to further the understanding of visual mechanisms.

Many years ago, Snellen's findings from a testing of a large group of young men were used to establish what was to be considered normal visual acuity. The standard test distance was 20 feet. It turned out that the majority of the subjects could see a separation between two portions of a target that subtended a visual angle of one minute of arc. Since such subjects could see at 20 feet what one would expect them to see at 20 feet, their visual acuity was called 20/20. Such subjects were able to resolve an absolute space interval twice as great as a given one from twice as far away or three times as great from three times as far away. The remaining subjects of Snellen's test required greater or lesser target-element separations for their resolution threshold. The subjects who required separations of 2 minutes of arc at 20 feet were called 20/40, for the normal subjects could pass the same test at 40 feet. To put it in other words, the subjects with subnormal vision were designated in terms of how far away the normal-vision subjects could be and still see the target-element separations. Hence, we find that there are people who have visual acuities of 20/30, 20/40, 20/100, 20/200, or some other of many designations, depending upon the minimum visual angle between target elements which they can resolve.

Clinic targets

The targets used in the clinic are generally rows of letters with elements separated by known visual angles. It is easy for the subjects to indicate whether they are seeing properly simply by calling out the names of the letters. Such targets have their limitations, however, for not all letters are of equal difficulty because of their intrinsic shapes as well as the separations of their components. Since alphabet letters are familiar, the subject is aided in guessing, introducing a biasing factor.

Level of illumination of the target chart is also a factor in the recognition of the targets, particularly if other portions of the overall visual field are illuminated at levels different from that of the chart. Intensity contrast between the target and its ground is a specific factor in visual acuity. Intensity contrast is often spoken of in a confusing way, for it is a term used not only to designate difference in the photic flux reaching the eye from two adjacent portions of the target field, but it is used also to refer to the

observed difference in brightness of the two portions of the field. Thus, in one case contrast is a property of the stimulus, and in the other it is a property of the sensory experience (the perception). When we say intensity contrast, we shall be referring to the stimulus. When we say brightness contrast, we shall be referring to the sensory experience.

Laboratory targets

For testing visual acuity in the laboratory, several different kinds of target are used: (1) a grating, or a field with contrasting stripes of equal width; (2) a broken circle, or Landolt C; (3) a pair of parallel bars; (4) a single fine line on a homogeneous background; (5) a single area, such as a disk on a homogeneous field; and (6) an interrupted contour by which vernier visual acuity is studied (Fig. 3.4). When single disks or single fine

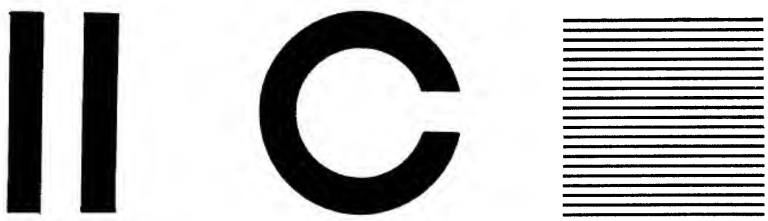


Fig. 3.4. Visual acuity targets. For parallel bars the separation between them is a critical feature. In the Landolt C the gap is the critical feature. In a grating the width and separation of the lines is critical.

lines are used, the separations between the opposite borders of the disks and between the lines are the critical features. In the case of the single disks, visual acuity and threshold target size become identical.

In the laboratory, visual acuity is stated not in the terms described for the clinic but in terms of the minimal visual angle that the relevant elements in the target must subtend in order to be seen, or resolved. Thus visual acuity is the reciprocal of the visual angle measured in minutes of arc. The ability to resolve target components of one minute is a visual acuity of 1; the ability to resolve those of 0.5 minute is a visual acuity of 2.

Figure 3.5 shows the relation between the threshold target size and contrast in which the target has a diffuse reflectivity of 3 percent and the backgrounds range in diffuse reflectivity from 3.4 to 80 percent. Each of the three curves is for a different level of illumination. It will be seen that the threshold size varies considerably for the different reflection values of background, that is, for the different contrasts between target and background.

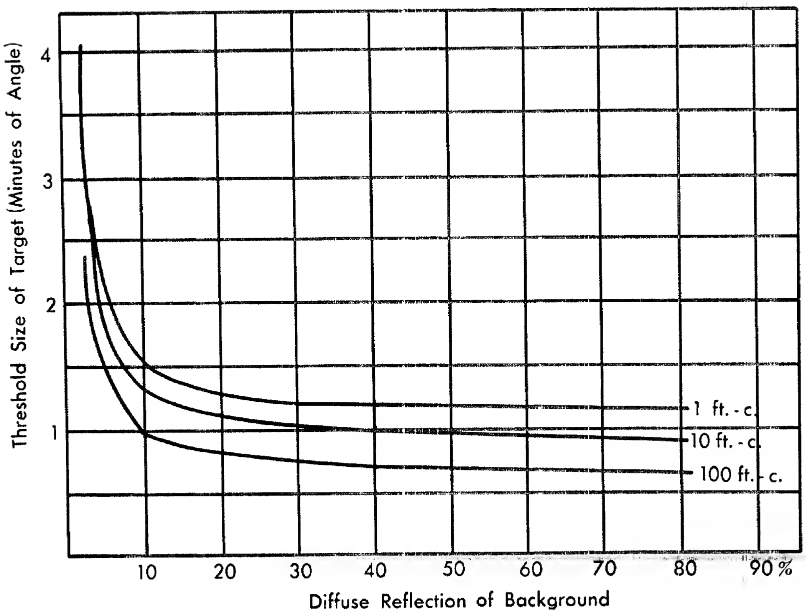


Fig. 3.5. Relation between the target size and reflection factor of the background for each of three levels of illumination: 1 foot-candle, 10 foot-candles, and 100 foot-candles. The diffuse reflection factor of target is 3 percent. (Data from M. Luckiesh. *Light, vision, and seeing*. Princeton, N. J.: Van Nostrand, 1944.)

Figure 3.6 turns the same information into visual acuity values. It will be seen that visual acuity varies considerably over the contrast range used. Both of these graphs were constructed from data presented by Luckiesh (1944). He has given a good summary of the relationship between target contrast, illumination, exposure time, and the behavioral results of visual acuity and size threshold. Its substance is as follows: as target illumination varies from one to 100 foot-candles, threshold size varies from 15 to 5 minutes of arc for low contrasts in the target and from 1.1 minutes to 0.6 minute for high contrasts. Under the same two sets of conditions, visual acuity varies from 0.067 to 0.200 and 0.90 to 1.67, respectively. For targets with low contrasts and varying exposure time, from 7 to 300 milliseconds, threshold size varies from 20 to 13 minutes, visual acuity from 0.050 to 0.077. With the same ranges of exposure time, but with high contrasts, threshold size varies from 1.3 to 1.1 minutes, visual acuity from 0.77 to 0.90.

GRATINGS AND BROKEN CIRCLES. Shlaer (1937) determined the relation between visual acuity over a background illumination range of about 8 log

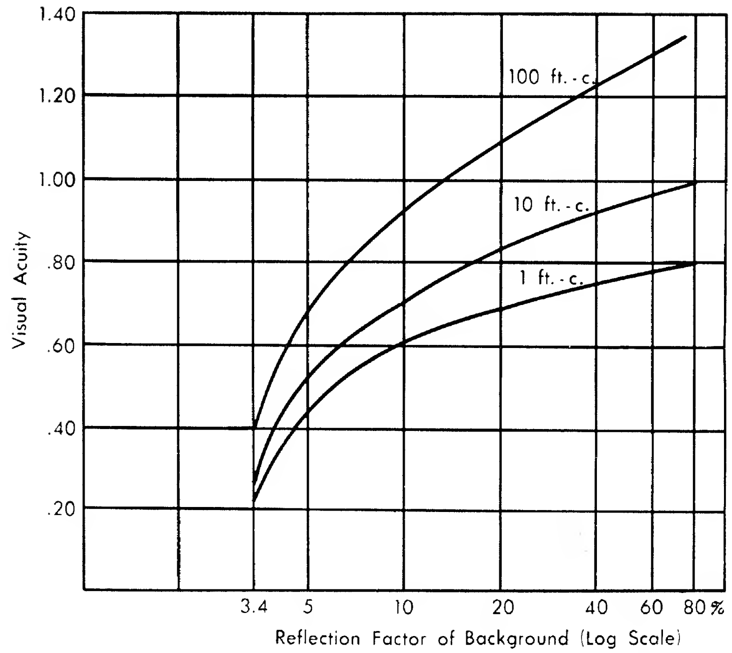


Fig. 3.6. Visual acuity for a target having a diffuse reflection factor of 3 percent for various background reflectances and at each of three different illuminations: 1, 10, and 100 foot-candles. (Data from M. Luckiesh. *Light, vision, and seeing.* Princeton, N. J.: Van Nostrand, 1944.)

units for a grating and also for a broken circle, or Landolt C, with a background subtending a visual angle of 30°. Thus, he was measuring the effect of a virtually nonluminous (or "black") test figure on a luminous field. Figure 3.7 shows the results. The grating provided for higher visual acuities under about 7 trolands[3] and lower visual acuities above this illumination.

The greatest acuity possible with the grating was 30 percent lower than with the open circle. Shlaer showed that with an aperture of less than 2.33 millimeters the pupil is the limiting factor in the resolution of grating, whereas, when the aperture is larger than that, the size of the central cones governs it. Various other workers studied this matter but did not use artificial pupils and failed to use a single viewing distance. These factors lead us to use Shlaer's work as the standard for visual acuity for dark targets on light backgrounds.

Fisher (1938) measured visual acuity for a grating in a 2° foveal area when the intensities of the area were 0.193, 10.97, and 318 trolands.

[3] A troland is a unit of retinal illumination that takes into account pupil size as well as target intensity. If the pupil aperture were one square millimeter and the target intensity were one candle per square meter, the retinal illumination would be one troland.

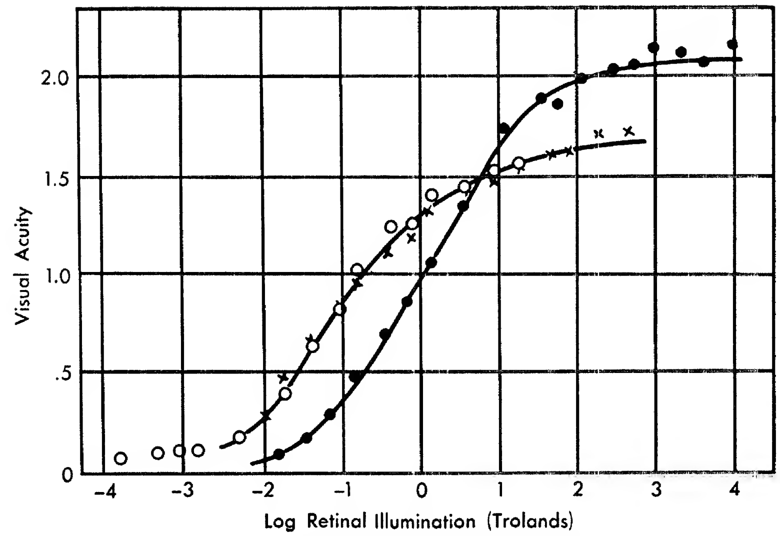


Fig. 3.7. Visual acuity as dependent upon retinal illumination. The filled circles represent the outcome with the C target. The open circles and crosses represent the outcome with the grating target. (S. Shlaer. The relation between visual acuity and illumination. *J. gen. Physiol.*, 1937, **21**, 185–209, Fig. 2.)

Monocular fixation, with a 2-millimeter artificial pupil, was used, while the other eye was confronted with a uniform field of low intensity. Annular surrounds varying both in subtended visual angle and intensity were also employed for the measurements. The radial widths of the annuli were 2.4°, 4°, 7.4°, 12.4°, and 20°, while their intensities were 0.0566, 0.193, 10.07, 318, and 8560 trolands. Under these conditions the results were as follows. When the annulus was more intense than the test area, visual acuity became poorer with an increase in the size of the annulus. When the annulus was less intense than the test area, visual acuity became better with an increase in the size of the annulus. When the two were equally intense, changing the size of the annulus had no consistent effect upon visual acuity. This last effect was similar in principle to one of Shlaer's experiments.

PARALLEL BARS. Wilcox (1932) used conditions quite different from Shlaer's. He used light targets on dark backgrounds as well as the opposite, and he used parallel bars instead of broken circles or gratings. His results are shown in Fig. 3.8. The lefthand curve shows the results with dark bars; the righthand curve shows the effects when the intensity (or luminosity) relations between bars and ground were reversed. It will be noted that up to a certain point increase in illumination favored visual acuity, and beyond this a reversal set in.

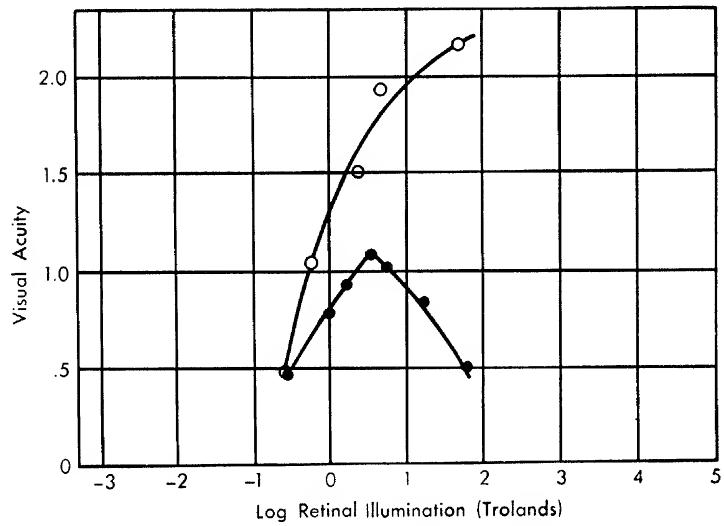


Fig. 3.8. Visual acuity for parallel bars. The open circles are for dark bars on a light background. The filled circles are for light bars on a dark background. (Modified from Wilcox, in S. H. Bartley. *Vision: A study of its basis.* Princeton, N. J.: Van Nostrand, 1941.)

Fry and Cobb (1935) found that broad and narrow bars do not produce like results when used to test visual acuity. They used two pairs of bars; the bars in the one pair were 1000 seconds in width, in the second pair 168 seconds in width. Their lengths in both cases were 2000 seconds. The results are plotted in Fig. 3.9, in which it is shown that, as the intensity of the bars is increased from a very low level up to 3 foot-candles, visual acuity first rapidly rises, but for the narrow bars it falls again very slowly. For the wide bars, it continues to ascend slowly after the first rapid rise. To explain this, they used the Fry-Bartley (1935) principle—namely, that physiological contour processes underlying the images of parallel target borders interfere with each other.

The production of threshold edges in perception is undoubtedly interfered with by the existence of two closely spaced parallel borders such as those of the bars. This makes the width of the bars a factor in the determination of visual acuity (see Fig. 3.9). When the bars are wide, the opposite borders of the bars themselves are removed far enough from each other to interfere very little. When the borders are close to each other, as in N, the contour processes responsible for seeing edges interfere with each other as much as or more than the smallness of the distance between the bars. But in W, the opposite borders of the bars in the target are far apart

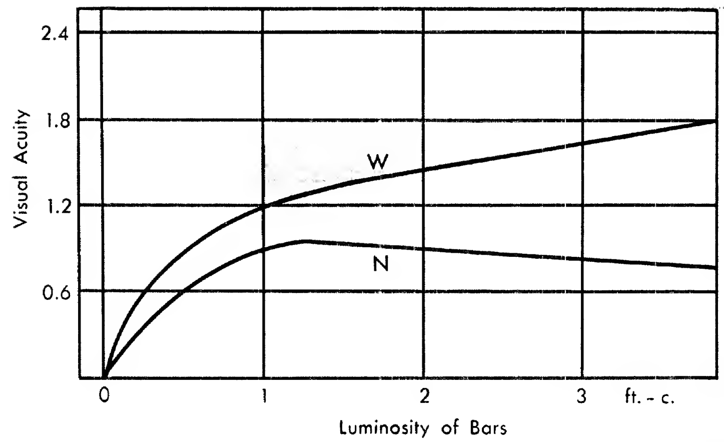


Fig. 3.9. The effect upon visual acuity of varying the luminosity of two bars on an unilluminated background. W is the result with wide bars (1000 seconds in width), N with narrow bars (168 seconds). (Adapted from Fry & Cobb, in S. H. Bartley. *Vision: A study of its basis.* Princeton, N. J.: Van Nostrand, 1941.)

and do not elicit contour processes that interfere as much with each other as in the case of target N.

FINE LINES. Hecht and Mintz (1939) studied visual acuity by using a fine line whose length subtended a visual angle of from 12.5° to 19°. This target was presented on a background subtending the same visual angle as the line. With a background range of from 0.00000603 to 30.2 millilamberts, the visual acuity varied from 10 or 11 minutes to 0.5 second. This was a range of 1320 to one. Putting these values into the notation given earlier in the chapter, the visual acuity ranged from about 0.09 to 120. It will be remembered that 1.0 is the order of normal visual acuity with Snellen letters in a clinical situation.

FACTORS AFFECTING VISUAL ACUITY

Retinal mosaic

The relation of visual acuity to the retinal mosaic is of fundamental significance. The retinal mosaic is one of the limiting factors in determining the smallest angular separations that can be seen between target elements.

The results that Hecht and Mintz (1939) obtained went far beyond the expectations and findings of earlier workers. It was once thought that for two portions of a visual target to be seen as separate, their images on

the retina had to be separated by at least one row of cones. If this were true, then the finest resolution obtainable could be calculated beforehand by finding out the cross-sectional size of cones and their separation, if any. This was done, and hence certain expectations were stated.

Let us examine Fig. 3.10 to see what the retinal mosaic is like in terms of angular subtense. At the top of the diagram, the distances subtended by cones are indicated. At the bottom, the distances in microns (1/1000 mm.) are given. In the lower part of the diagram are three short horizontal bars, each representing the width of fine wires as they would be projected in retinal images if the images corresponded strictly to the subtended visual angles. It happens, however, that retinal images are not precise target representations but instead are somewhat blurred. That is, images are not abrupt but taper off at their bounds.

The upper curve represents the distribution of the light on the retina in the image of the finest wire, the one represented by the shortest hori-

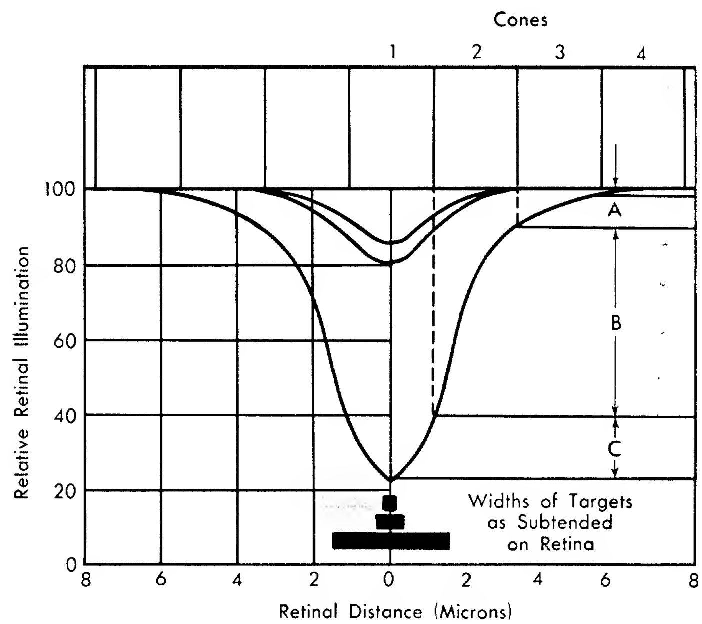


Fig. 3.10. Curves showing relation of images of target to foveal cones. A, B, and C show that the intensities of illumination on adjacent cones are unlike. Cone 1 is illuminated somewhat more intensely than cone 2; although cones 3 and 4 are not so intensely illuminated, the difference between their illuminations is very great. (Modified from S. Hecht & E. U. Mintz. The visibility of single lines at various illuminations and the retinal basis of visual resolution. *J. gen. Physiol.,* 1939, **22,** 593–612, Fig. 3.)

zontal bar. Whereas the width of the wire in the image covers only a portion of the width of a single cone, the tapered image not only covers a whole cone but tapers off over most of the cone to either side of it.

The theory that lies back of visual acuity, or the detection of the line as such, is that in order for a fine-line target to be visible its image must affect a single row of cones either greater or less than the row to either side of it. That is, for threshold detection there must be a threshold *difference* between the energy impingement on the central row and on its neighbors to either side. Some authorities think that this difference need be no greater than 1 percent.

The finest wire that can be detected is so fine as to represent a visual angle much less than that subtended by a single cone. According to Fig. 3.10, the image of the wire tapers and extends beyond the distance represented by the angular subtense of the wire. The fineness of the wire controls the steepness of the taper and the critical taper is formed by wires finer than one cone in cross section. Were there no taper, a very fine wire would cast an image that would not be broad enough to cover a row of cones. The finer the wire is, the less is the radiation delivered to the one row of cones. Hence, as finer and finer wires are used, intensity becomes the prime factor in determining whether such wires can be seen. Once target fineness falls below the width of a cone, no further distinctions can be made in spatial terms. This does not seem to be the way visual acuity relates to target subtense.

Pupil size

Pupil size influences three features of visual function: sharpness or definition of retinal image, resolution of detail, and experience of brightness. The definition of a lens increases as aperture decreases; thus, as the pupil constricts, sharpness of image is increased. Resolution increases as lens size increases, and thus resolution improves as the pupil dilates. It turns out, however, that in the eye these factors just about offset each other over a considerable range of pupil size. Visual acuity, with constant brightness of the object seen and constant intensity of the retinal image, does not change greatly with pupil diameters ranging from 2 to 6 millimeters. This is actually most of the range over which the pupil varies in the usual day-to-day situations.

On the other hand, a person may improve his ability to see certain targets in low illumination by supplying himself with an artificial pupil. For example, if one is viewing a projection screen in a weakly illuminated room, the material (tables of numbers, for instance) may not be legible. If one punches a small hole in a card and views the screen through it with one eye (the other eye being closed), it is likely that he will be able to read the tabular material.

Age

In the literature, we find various statements indicating that in older people a drop in illumination affects visual acuity whereas in younger people no great effect is brought about in this way. Is it that the pupils of young and old behave differently to manipulations in level of illumination, or is some other factor responsible?

The following are representative values given by Luckiesh (1944) regarding the relation between visual acuity and age. Beginning with the age of 20 years, visual acuity is 100 percent (normal = 20/20); at the age of 40 it declines to 90 percent; at 60 it is down to 74 percent; and at 80 it is down to 47 percent. It is obvious that such figures are only statistical and may not apply to any given individual but, on the other hand, they indicate that in general considerable decline is to be expected.

Taper or blur of retinal image

The discrepancy between the visual target and its image on the retina must be considered in the matter of visual acuity. Ideally, the natural image is described as a copy of the visual target, but it is not in fact such a copy. Whereas targets may be said to possess abrupt borders, their images do not. The images are at best somewhat tapered or blurred. There are various optical reasons for this that involve the nature of the mediating tissues.

The laws of chromatic and spherical aberration are generally used to calculate the pattern or degree of blurredness, but such calculations do not take into account the slight oscillatory action of the eye itself, which introduces a blur factor of its own. Fry and Cobb (1935) took this into account by a direct measuring method. They assumed that the center-to-periphery intensity distribution in the image of a homogeneously luminous target would be a taper described by a well-known equation. To check on the matter, they obtained the intensity thresholds of bars A and B in a visual target. Bar A was made so wide that greater width did not reduce the intensity threshold. Bar B was made so narrow that intensity and width were made reciprocal in determining threshold. The investigation showed that any width greater than 224 seconds of arc was sufficient for bar A and any width less than 30 seconds of arc was sufficient for the latter. By comparing the results with what the ideal results would be if there were no taper, and by using the equation, they were able to calculate the magnitude of the taper.

It can be said that the threshold response to a long, narrow line used as a target depends not only on the intensity (or luminosity) of the line but also on its width. It is evident that some spread of radiation forms the

image. Fry and Cobb's study was taken to invalidate the assumption that the intensity of the center of the image remains constant for various bar widths. In Fig. 3.11, the center-to-periphery taper of the retinal image is

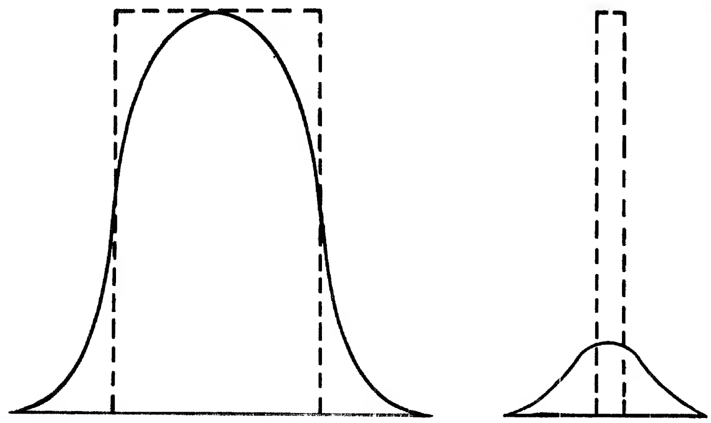


Fig. 3.11. Relation of target width to intensity of retinal image. Broken lines represent distribution of radiation in target, solid lines the distribution radiation in image. (S. H. Bartley. *Vision: A study of its basis.* Princeton, N. J.: Van Nostrand, 1941.)

shown. Reducing the *width* of the line, which is already very narrow, would be expected to lower the *intensity* at the center due to the blurring.

Stray illumination in the eye

In addition to the factors producing slight blur of the retinal image, stray illumination of the retina from dispersion of radiation at the junctures of the various media (the inside of the cornea, the vitreous humor, aqueous humor, and lens) occurs in considerable amount, so that even an image of a target subtending only a few degrees of visual angle provides a broad taper of general illumination which, when target luminosity is high, becomes an effective stimulus over large portions of, if not the total retina. In fact, it may be that the existence of such a total, determines whether such phenomena as "autokinetic movement" occur. This is to say that this stray illumination and thus the activation of the whole retina may be the basis for the perception of a stable visual field. This idea has not as yet been put to a quantitative test.

Bartley and Fry (1934) were aware of the stray illumination in the eye and used an indirect method to study it. A luminous target was placed in the peripheral part of the visual field and the amount of stray illumination falling on the fovea was measured by the change produced in the differential

threshold there. The differential threshold target was a ring-annulus. The change brought about by the peripheral target on the differential threshold at the fovea was compared with the effect on the threshold produced by a known level of illumination cast directly on the fovea. The peripheral target was placed at a series of distances from the fovea and the threshold effects were found for them. From this was plotted a curve representing the relative amounts of stray light produced at various distances from a target of known size and luminosity.

Later, Bartley (1935) measured stray illumination in the eye by using excised eyes of albino rabbits. Such eyes were placed on a pedestal in a dark room facing a lamphouse with a luminous disk as a target, which was imaged on the retina of the eye. The whole eye was thus also internally illuminated in addition to the image, which of course shown more brightly through the translucent wall of the eye. The level of luminosity of the eye wall was measured from the outside at various distances from the image itself. Likewise, the factors of image area and intensity in producing the luminosity of the eye wall were measured.

Considerably later, Boynton, Enoch, and Bush (1954), also measured stray illumination in excised eyes. Their equipment and technique were considerably more precise than Bartley's, but the study confirmed his findings in general.

PERCEPTION OF EDGES

When the photic radiations reaching the eye from two portions of a target are unequal, the observer usually perceives them as different levels of lightness and these areas may be perceived as having abrupt edges. However, if the target presentation is made in two stages—one area shown before the other—the edges may develop into a blur. If the area presented first is surrounded by the area presented next, the inner area may disappear. The manipulation of the time interval between the presentation of the first target portion and the second produces even additional changes. Thus we may say that timing of stimulation is a crucial factor in the perception of surfaces and edges. For examples of this, we may turn to some experiments of Werner (1935) and Bartley (1939).

Werner presented pairs of targets of many forms varying from circles and disks to irregular and incomplete forms. In one case, for example, a target perceived as a solid black disk when presented alone was briefly presented on a light background (Fig. 3.12). In about 150 milliseconds another target centered on the same point in the visual field was presented. When this target was presented alone, it appeared as a black ring. With the 150-millisecond interval elapsing between the presentation of the first and second targets, the disk was never seen—that is, the area within the ring was not black. When the temporal sequences of the targets were reversed,

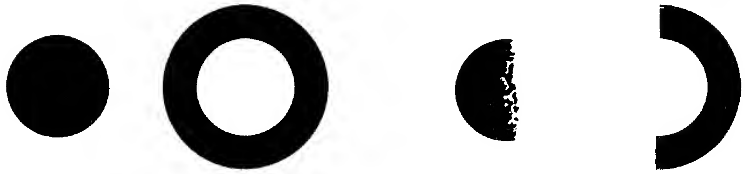


Fig. 3.12. Werner's figures. The disk and ring are presented in temporal succession, and because their centers are at the same point the disk occupies the same area as the space within the ring. Under some conditions, when half the ring is presented only half the disk is seen and then with a tapered gray surface, as indicated. (H. Werner. Studies in contour. I. Qualitative analyses. *Amer. J. Psychol.*, 1935, **47**, 44–46, figs. 5, 9.)

the black disk *was* seen. The timing of the disk-ring succession that eliminated the seeing of the disk is more-or-less critical. If the rate of succession is slow, the disk will be seen to precede the ring. If it is more rapid, the ring is seen with a darkened inner field. If it is still more rapid, the inner field, which might have been expected to be a dark disk, lightens, and it may become lighter in some cases than the light field outside the ring.

It is possible to interchange the intensity relation between disk or ring and the ground on which they are made to appear, so that the figures become light and the ground black. In this case, the original phenomenon will still occur. That is, the object that ought to have emerged in contrast to the ground will not do so.

It will be noted that the second figure, a ring, had both an inner and an outer edge; [4] whereas the disk, when it exists, of course has only an outer edge. Since the results differed according to which of the two targets was presented first, they indicate that the outer border of the second target played a part in the outcome. The same results, it may be added, occurred whether both targets were presented to one eye or to separate eyes.

This may be what actually underlay the outcome. When the disk target is presented first, but is followed very soon by the ring target, the border contour for the disk does not have time to form. Since the contour process has not formed in the only time given it to do so, the ring simply develops as a ring without the disk ever being seen. At a critical stage in the presentation of the two components of the target, the contour process for the second component (the ring) may utilize the decaying contour process for the first component to accentuate its own inner edge, since the direction of the two gradients would be the same. This account is based upon the principle originally recognized elsewhere in threshold studies

[4] For the sake of clarity, we shall call the bounds of the target its borders and the bounds of the visual object its edges. Thus it will be clear whether it is target or perception that is being referred to. We shall refer to the intervening process in the nervous system that is responsible for the seeing of objects and their edges as a contour process.

that contour processes must develop and complete themselves before differences in brightness of two areas can be distinguished. Whatever depresses or precludes edge formation precludes the appreciation of the brightness a surface would have.

We may continue with the account by detailing the possible process events when the order of target presentation is reversed. The temporal interval between the presentation of the two targets is not critical. Regardless of how soon the disk target is presented after the ring target, the disk appears as a black surface. That is, if the disk target is presented *before* the contour process for the inner edge of the ring is developed, it is simply forestalled and never completed, and the whole figure is seen as a large disk whose outer edge has time to develop before the presentation of the disk target. This event, by changing the illumination within the ring, obliterates the condition for its continuance.

Bartley's (1939) experiment about to be described had certain features in common with Werner's. Bartley used a target arrangement that provided for seeing a figure of two parts: a disk that was surrounded by a ring whose inner edge was the outer edge of the disk. The stimulus flux for the disk could be controlled so that a light disk would alternate with a dark one while being surrounded with a gray or only medium-bright ring. When the intensity level of the ring target was raised above the mean value of the two disks, the light phase of the disk alternation became less predominant than the dark phase. When the level of the intensity of the ring target was reduced below the mean, the light phase became predominant. Along with this shift in predominance, a difference in edge properties of the two phases of the disk developed. The predominant phase possessed a sharp edge; the "diminished" phase lacked an edge and became a mere "shadow." The predominant phase seemed to occupy more time, thus taking up most of the cycle.

In order to subordinate the light phase of the disk and make the dark phase predominant, the intensity of the ring target (when alternation frequencies are low) must exceed not only the Talbot level (see Chapter Four, p. 106) but the photic intensity for the light phase of the disk. Increasing the alternation rate reduces the level of the ring target needed until it reaches Talbot level. The light phases of the disk grow less bright as the critical flicker frequency (CFF) is reached. To have the light phase predominate, the target conditions just described must be reversed.

It has been found that the distance between two target border processes has a great deal to do with the emergence of object edges in perception. This was measured by the intensity values in the different parts of the field required for edges to emerge; that is, it was measured in threshold experiments. For example, the target intensity differences between the two parts of the target producing a small disk figure on a large disk ground are diminished as the size of the ground is increased (its border is shifted farther and farther away from the border of the inner-lying disk). In Fig.

3.13 the distance between the two borders is greater in the righthand target than in the lefthand one. The question, then, is whether area or distance

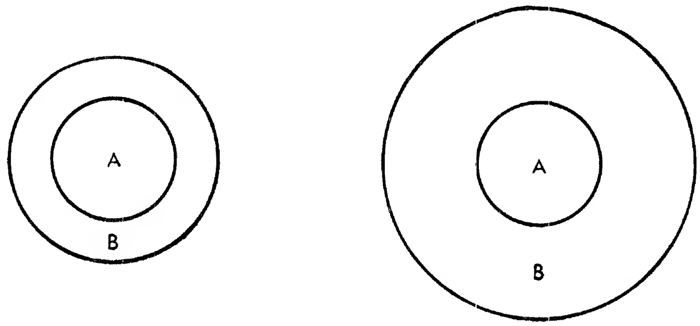


Fig. 3.13. Targets made up of a constant central disk area A and a surrounding ring area B that is manipulated in size.

between borders makes the above-mentioned difference in threshold. It was long customary to attribute the difference to area. Fry and Bartley (1935) showed that contour processes were responsible.

The first step in this demonstration was use of the target shown in Fig. 3.14. There were three stimulus areas, A, B, and C. Areas B and C were

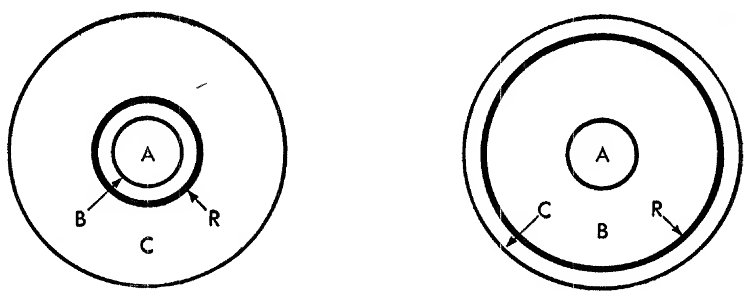


Fig. 3.14. Targets made up of a central area A and an outer area B plus C that is constant. The distance of the border of ring R from the border of A is varied. (G. A. Fry & S. H. Bartley, The effect of one border in the visual field upon the threshold of another. *Amer J. Physiol.*, 1935, **112**, 414, 421, Fig. 3.)

separated by a thin ring, R, the size of which varied as it was moved closer to A or closer to C. Varying the ring size did not affect the constant total area BC, lying outside A, but it did manipulate a border in the vicinity of A. It was supposed that since total area outside A was held constant, no shift in the threshold for the emergence of A as brighter than B would occur, if the customary area explanations were to apply. On the other hand,

since a border was being varied in distance from the outer border of A, a threshold manipulation would occur, if the contour process explanation were correct. Experimentation tallied with the contour process expectation. Further manipulations of target conditions were made, and all gave results in line with the idea that two parallel contour processes inhibit each other; that is, they require greater intensity differences on their two sides for the emergence of perceived edges. The same investigators found that non-parallel borders—that is, those at right angles to each other—actually resulted in facilitation rather than inhibition.

EYE MOVEMENT AND THE RETINAL IMAGE

Stabilizing the retinal image

The earlier presumption in much of the work on and discussion of visual acuity was that the eye is motionless when viewing a stationary target. In more recent times, it has come to be realized that, even with the best of fixation, the eye is not motionless. Tiny oscillations too small to be noticed with the observer's naked eye take place. Thus ways have had to be found to prevent the image from executing tiny oscillations back and forth across the region of the retina on which it was projected.

One way to preclude imperfections of fixation (that is, unwanted departures from good fixation and tiny, directly unobservable oscillations of the eye) is to use a special kind of target. Pritchard (1961) attached a target to the eye by means of a contact lens on which was mounted a miniature optical system that projected an image on the retina. Thus, with every movement of the retina, great or small, the image moved too and the usual spatial disjunction between image and retina was obviated.

Riggs, Ratliff, Cornsweet, and Cornsweet (1953) earlier used a very different device whereby the image remained in a fixed location on the retina regardless of eye movements (Fig. 3.15). A photic beam reflected from a mirror attached to a contact lens was projected onto a screen. The beam was then reflected back to the eye through a portion of the contact lens not obscured by the mirror. The optical system was such that for every movement of the eye a compensating movement of the beam reaching the eye was produced. Thus the net result was that the image remained in the same location on the retina.

Effects of eye movement on visual acuity

Even in fixation the eye exhibits tiny oscillations; this motion would seem to affect visual acuity. According to Riggs (1965) (1) the movements may be so tiny that they have little effect or (2) they may cause a "blurring" of the retinal image much as the jiggling of a camera blurs the resulting negative and print or (3) they may "scan" the borders of the target

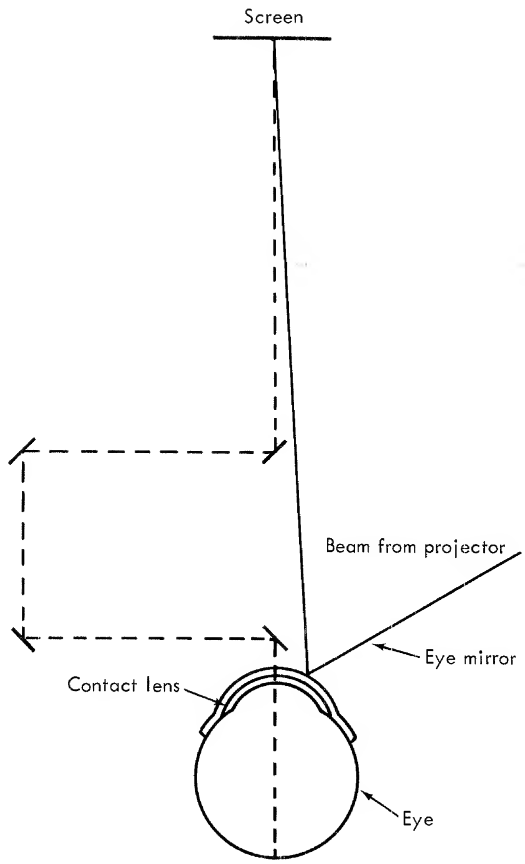


Fig. 3.15. Optical arrangement whereby a visual image is maintained on a fixed portion of the retina. (L. A. Riggs, F. Ratliff, J. C. Cornsweet, & T. N. Cornsweet. The disappearance of steadily fixated visual test objects. *J.O.S.A.*, 1953, **43**, 495–501, Fig. 2.)

and thus accentuate the differential neural activity beyond that resulting from a static image.

Riggs, Armington, and Ratliff (1954) found that during one second of time a retinal image is carried over about 3 minutes of arc, whereas in 0.10 second the typical excursion is about 25 seconds of arc, just about the angular subtense of a cone. In 0.01 second, the typical sweep is 5 seconds of arc. This means that in 0.10 second the movement of the image is less than the separation between adjacent cones in the center of the retina. The critical duration for a visual act in which acuity is crucial is about 0.10 second. Thus, during this interval the movement is less than the separation between adjacent cones.

The effect of these movements on visual acuity has been studied in two ways: (1) by ascertaining the instantaneous value of visual acuity by presenting the target for a fixed interval of time and measuring the concurrent eye movement (Ratliff, 1952) and (2) by counteracting or exaggerating the eye movements and determining the consequent effects (Riggs, Ratliff, Cornsweet, and Cornsweet, 1953; Keesey, 1960). Such experiments have shown no evidence that eye movements improve visual acuity; they show some evidence to the contrary.

Ratliff (1952), recording fine tremor, larger waves, and slow drifts and abrupt saccades (involuntary eye movements in reading print) showed that the drifts hindered visual acuity. Optically compensating for the eye movement in one case, doubling the effect of eye movement in another, and using the uncompensated condition in a third, Ratliff, found that counteracting eye movement produced little effect. When any effect was obtained, it was in the direction of improvement. On the other hand, keeping the image fixed on the retina caused the target to fade from view quite quickly. The condition of optical exaggeration of movement improved the maintenance of vision over extended periods of time.

Keesey (1960) showed that optically "stopping" the motion of the image had little effect on visual acuity regardless of the presentation time, which he varied from 0.02 second to 1.28 seconds. He showed that in each of the two conditions ("stopped" and free-movement images), visual acuity did not improve with presentations beyond 0.2 second. Thus it can be said that eye movements that normally take place during 0.2 second do not have much effect on visual acuity, when measured either by target detection, localization, or resolution. Marshall and Talbot (1942) had supposed that scanning a visual target was necessary to achieve a maximum degree of discrimination.

BODY-PROCESS FACTORS IN VISUAL ACUITY

Marshall and Talbot (1942) considered the several possible factors—optical, motor, and neural—that underlie visual acuity. They listed:

1. Diffraction in the retinal image produced by the pupil of the eye, resulting in a gradient or taper of illumination intensity at regions corresponding to target edges, fine lines, and other discontinuities.
2. Physiological nystagmus, the tremor complex that we have just discussed. They supposed that in accord with this complex of frequencies and amplitudes of excursion, graded intensities of image border would be applied to the impinged-upon receptors to produce characteristic impulse frequencies in them.
3. Reciprocal overlap of adjacent pathways, another factor increasing the effect of photic excitation.

4. The neural recovery cycle, which in its own way would facilitate or depress transmission at synapses.

5. Multiplication of initial unit paths at the lateral geniculate body (a station on the way to the cortex) and at the cortex, producing in the cortex a more finely grained mosaic than is characteristic at the retina.

6. Factors, expressed in terms of threshold, that by-pass more or less the pattern of activity already implied.

7. The factors of range in neural activity spanning about two logarithmic units of stimulus input intensity.

We may add that not only pupillary diffraction of illumination but also stray illumination in the eye is involved in producing tapered retinal images. In fact, this latter factor plays a greater role in producing taper by broadening it beyond that produced by diffraction.

As far as the role of mystagmus is concerned, the findings of Ratliff and his colleagues and Keesey indicate a different role for tiny eye movements than Marshall and Talbot supposed. The neural mechanisms that produce these findings are not yet totally clear.

Studies on the response of specific cortical cells to motion of visual targets by Hubel and Wiesel (1965) and to the oscillatory motions of the targets by Burns, Heron, and Pritchard (1962) have produced certain interesting results. In Hubel and Wiesel's study, for example, responses were maximal when motion was in a direction perpendicular to the axis of the cell recorded from. Speed and direction of movement were also factors. Some cells were affected differently by opposing directions of movement. The caution must be injected that one must not infer that these results accrue simply as intrinsic cell properties; they must result from contextual influences as well as the cells themselves. The reciprocal overlap discussed by Marshall and Talbot undoubtedly plays a role in relating the optical pattern to a consequent neural pattern whereby to carry information a step further toward the cortex.

Recovery cycles of individual neural units would seem to be involved in augmenting (facilitating) and in depressing activity representing various parts of the optical image. Tiny eye movements, while not improving visual acuity, may play a role in the ultimate disappearance of the target that has occurred in conditions of "stopped" movement.

It had been asserted that there is a one-hundred-to-one multiplication in the spatial representation of a single point as one goes from retina to cortex. This is the basis for the finer representational mosaic that Marshall and Talbot refer to in item 5 of their list.

The factor of threshold is a way of recognizing the contribution of the total organism to visual acuity.

The outlook of Marshall and Talbot involves the assumption that in the nervous system there must be something that corresponds to the edges

of objects, or target items, to fine lines, and to other details within them. These are all variations in intensity of input (or illumination). The factors these authors discuss are taken to be means whereby abruptions or intensity transitions are augmented neurally to compensate for the tapers in the retinal image (factors that run in opposition to abruptions of transition). They feel that the processes they describe accomplish this augmentation or exaggeration (Fig. 3.16). This may be the case, for we have to posit some kind of neural correlates to optical inputs. We do not have to employ a kind of isomorphism, however. As soon as the eye is reached, we

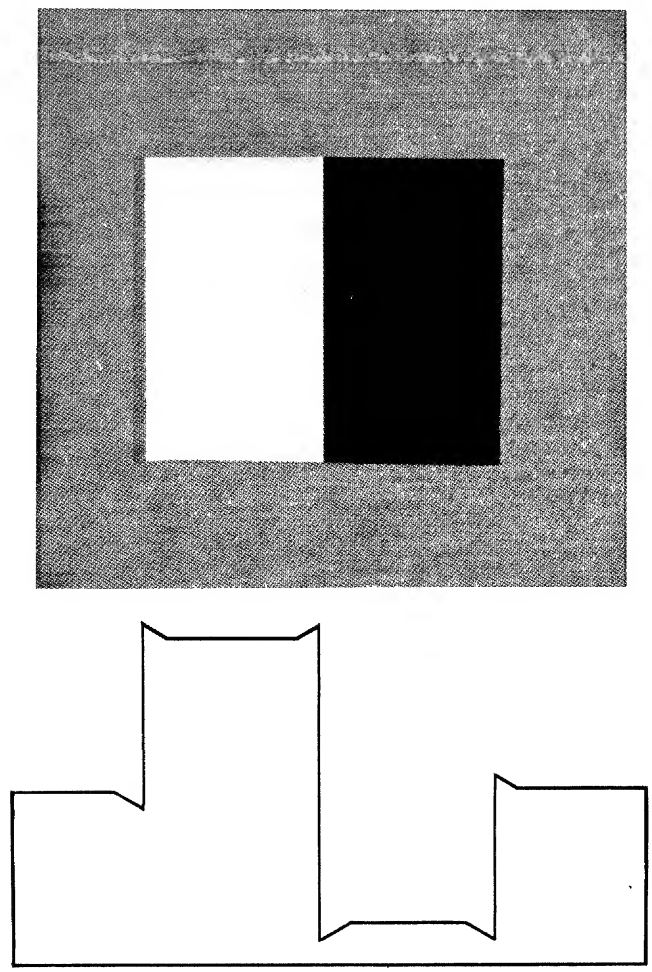


Fig. 3.16. Diagram showing Marshall and Talbot's explanation of the pattern of certain effects in the visual system relative to transitions from one level of illumination to another on the retina.

find that isomorphism is not demonstrated. The image tapers where what is seen possesses abrupt transitions. Since we no longer believe that what we see is a copy of "what is out there," we need not carry on an attempt to make anything in the train of events "copy" anything else. As yet, we have no understanding of what the neural correlates of optical or other events are like. Even if we were to succeed in getting the neural events in the optic pathway to "correct," or compensate for, the taper in the image, the copying in the nervous system would stop at the visual projection area and the rest of the neural events in the brain would be understood according to some other principle.

DYNAMIC VISUAL ACUITY

The determination of visual acuity as so far described has involved the use of stationary targets, for the attempt has been to ascertain the fundamental spatial relations in the function of the sense cells of the retina. However, visual acuity for moving targets has recently been studied by Ludvigh and Miller (1953). Visual acuity, under the conditions they used, is called *dynamic visual acuity*. Ludvigh and Miller's experiment was as follows. The subject, with his head immobilized, viewed a revolving mirror that disclosed a target that was effectively 4 meters from the eye. The rate of revolution of the mirror determined the velocity of the stimulus presentation as it swept past the eye. (Figure 3.17 shows how a revolving

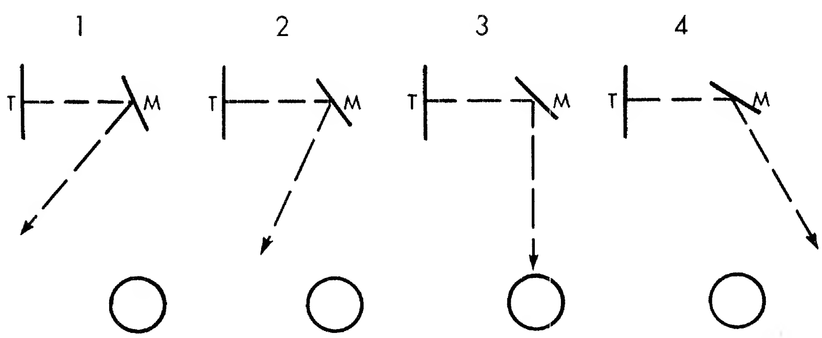


Fig. 3.17. How a revolving mirror can pass the radiations from a target across the eye and thus produce the equivalent of a moving target. Each circle is the same eye but at a different instant. From left to right, the target is in effect approaching the eye. At third from left it is in full view; at the far right it has passed by. M is the revolving mirror. T is the target.

mirror provides target motion.) The illumination of the target was held at about 25 foot-candles, with a background area that possessed a reflection coefficient of about 85 percent. The angular velocity of the sweep of the

radiation beam across the eye was varied from 10° per second to 170° per second. The total duration of the target presentation was 0.4 second in all cases, regardless of target velocity. The target was a Landolt C whose open portion was positioned randomly from trial to trial in one or the other of eight clockface positions. Figure 3.18 shows the results, which were repre-

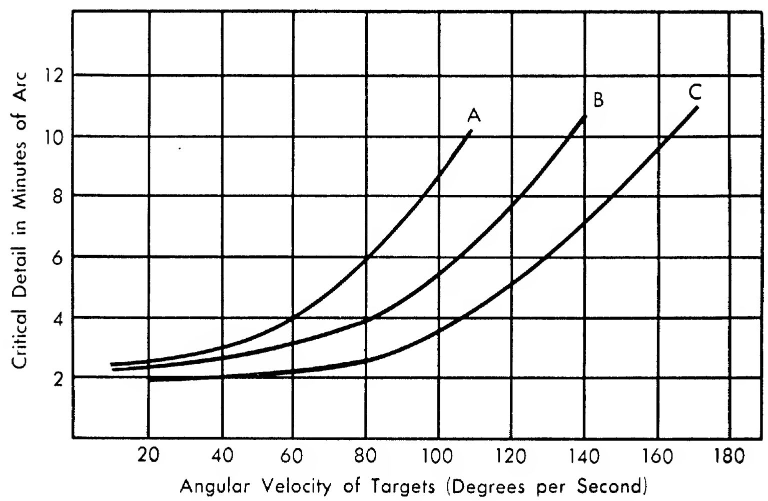


Fig. 3.18. Relation between visual acuity and the effective velocity of moving targets for each of three groups of observers A, B, and C. (E. J. Ludvigh & J. W. Miller. *A Study of Dynamic visual acuity,* Joint Proj. Rep. No. 1, Kresge Eye Institute Contr. Nonr. 586 (00), ONR Proj. Desig. No. 142–023, BuMed. Proj. NM 001067.01.01, 1953, Fig. 3.)

sentable by the equation $y = a + bx^3$, in which a is a measure of static visual acuity. This is of course small when static acuity is good. For high values of angular target velocities, y is chiefly assignable to bx^3, in which b is a measure of dynamic acuity. It is small when dynamic acuity does not decline rapidly as angular velocity is increased.

At an angular target velocity of 20° per second, acuity with vertical target motion correlated 0.50 with acuity for horizontal target motion. With angular velocity raised to 80° per second, the correlation rose to 0.72, and for 110° per second it dropped to 0.59. The fact that the dynamic visual acuities in the two directions correlated as well as they did was interpreted to mean that dynamic visual acuity was largely dependent on the efficiency of the overall ocular pursuit mechanism rather than on the strength or behavior of individual muscles as such. The results showed, too, that not all persons with equally good static acuity were similar in dynamic visual acuities for the various velocities.

VISUAL ACUITY AND PERCEPTION OF BRIGHTNESS

There are certain close relations between visual acuity and the perception of brightness. Both are the consequences of more than the optics of the eye and the intensive features of the photic input. Visual acuity has primarily to do with the spatial distribution of the photic input, but brightness is likewise dependent upon these very factors. Both visual acuity and brightness perception involve processes whereby edges are seen. On this account some of the problems and studies having to do with seeing edges have been presented in this chapter and others will be reserved for Chapter Four on brightness discrimination.

CONCLUSIONS

The discussion so far—involving as it does some concept of the retinal image and concepts as to what activity must be produced in the portions of the retina covered by the image—should lead to the realization that in the broad sense the term image need not be confined to optical effects. By way of the eye the organism obtains information from its surrounds. Information is first carried in the spatio-intensity configuration of the optical array reaching the retina. As has already been pointed out, the process of obtaining information is not quite the "copy" procedure that has long been implied in the simple, strict connotation of image. This raises the problem of what kind or kinds of differentiation (spatio-intensive) result in ultimate differences in neural activity in the cortex and enable the organism to perform articulately and effectively. Since one of the departures from ideal copying is taper at bounds instead of abrupt bounds, one can illustrate the problem by asking, for example, how gradual a taper can be and be informative (or useful) for the next stage in the series of processes intervening from receptor to cortex. The "copy" idea must obviously be discarded. What we should be looking for to replace it are invariant ordinal relationships between events at successive stages in the series from external input, or stimulus, to sensory end result.

By this time it should be evident that in presenting the various factors involved in visual acuity, we have reached the point at which other matters such as brightness discrimination and the perception of figure and form intrude. Instead of moving further into the study of visual acuity, we shall postpone these matters for appropriate chapters later on, even though the information we shall take up now may have been obtained by some of the techniques that have been central in this chapter. We refer particularly to techniques for stabilizing images on the retina.

SUMMARY

This chapter on the formation of the retinal image and on visual acuity has included a discussion of the various concepts involved in defining and measuring visual acuity. This included the concept of the visual angle and image formation in the eye. Because all eyes are not alike, emmetropia (the normal state) and the several anomalous conditions such as myopia, hyperopia, and presbyopia were defined and described. The oculomotor aspects of vision were also pointed out.

Various factors influencing visual acuity, such as those that pertain to the visual target itself and those such as age, pertaining to the perceiver, were dealt with, including the factors that have to do with the perception of edges.

Attention was given to the fact that conditions that compensate for the typical small oscillatory eye movements, which exist even under fixation, cause the fixated target to disappear.

The chapter concluded with a discussion of the body-process factors that underlie the fact that retinal images are neither sharp nor stable and with a discussion of dynamic visual acuity.

FOUR

Adaptation and Brightness Discrimination

The material in this chapter pertains to two basic features of vision, adaptation and brightness discrimination, and to some of the methodology involved in studying them. Adaptation is the adjustment of the eye and possibly other parts of the visual mechanism to the general photic intensity level it confronts at a given time. Brightness discrimination is the ability of the visual system to distinguish between the various intensity levels involved in a given pattern of photic input. Without these capacities there would be no vision as we know it.

The vertebrate eye and the human eye are capable of responding effectively to an enormous range of intensities of photic impingement. Brightness is the name for the experience that is correlated with intensity or luminosity. Brightness is thus a response term, while intensity and luminosity are stimulus terms.

Adaptation and brightness discrimination are nonetheless closely related. Whereas it may take a material amount of time perhaps varying from seconds to minutes to completely adapt to a given level of illumination, brightness discrimination requires only a very small fraction of a second to distinguish between and react to differences in intensity of illumination. Photochemically, adaptation and brightness discrimination are taken to be two aspects of the same mechanism at work.

Everyone knows that when one enters an unilluminated or weakly illuminated room, such as a movie theater from the street on a bright sunny day, he cannot see very well. In a few minutes, inability to see diminishes and objects begin to be fairly observable. This is the experiential or visual aspect of *dark adaptation*. An equally well known occurrence is the same initial inability when one passes from an unilluminated area to an

illuminated one, as when leaving the theater and returning to the sunny street. The process in this case is called *light adaptation.* The photochemical processes that go on in the eye are largely responsible for both forms of adaptation.

Since the amount of adaptation is determined by the photic level and the length of time exposed to it, it is important to take adaptation into account when attempting to understand visual response. The individual's perceptions and judgments of the degree of grayness or lightness, for example, are dependent first of all on adaptation level.

There are two ways that photic radiation may reach the eye. It may come directly from an independent source, such as fire, arcs, heated filaments, or glowing gas in fluorescent tubes, or it may reach the eye by way of reflection from surfaces. Radiation reflected from a surface of course reaches that surface before coming to the eye and the illumination of the surface in question may be more intense than the illumination of other surfaces around it or it may be less intense.

There are three ways that photic radiation may reach the eye from scenes. Part of it may come from an original source such as just mentioned, it may be reflected from specific sources receiving radiation from a general illuminant, or it may be reflected from a localized illuminant not cast on all the targets in the scene. It is worthwhile to know that differences in appearances—that is, differences in visual responses— come from these three origins.

As far as the observer or perceiver is concerned, one more factor must be added: the presence of conditions giving rise to perception of texture at the reflecting surface. Visual texture can be defined as lack of uniformity in reflectance of a surface, perceived as a physical property of the surface itself. A surface as judged mechanically by touch may have a texture that is not perceived visually, depending on whether the illumination is diffuse or arises from a localized source. Illumination from a localized source is called specular illumination. Tactually fine-grain roughness may be seen as only as a matte surface. On the other hand, visual texture may possess considerable coarseness. Whatever the texture may be, it is associated with the existence and position of the surface as a visual reality. Complete absence of conditions for texture would make it impossible to see surfaces.

STRAY RETINAL ILLUMINATION ("SCATTERED LIGHT")

It had long been assumed that virtually all photic radiation reaching the retina was focused in the image or images there. There was of course, consideration of image aberrations in which the boundaries of the images were not ideally abrupt, but beyond this the image was taken to be largely a copy of something in the external world.

In 1935, Bartley demonstrated that a considerable amount of the radiation reaching the eye arises from factors outside the imaging process. He made rough measurements of this illumination and with his associate, Fry, performed various experiments to show its action, that is, its role in determining the nature both of the electroretinogram (ERG) and the perceptual end results. Later, Boynton, Enoch, and Bush (1954) made more refined measurements of stray illumination and, in essence, confirmed the original ones.

The scattering of radiation in the eye provides the retina not only with an image but also with radiation that is nonfocused and covers the whole eye. For example, if the image of a target of restricted visual angle—let us say a small luminous disk in a dark field—is focused on the retina, the retina is not only illuminated in the disk image but receives radiation of some intensity or other on every portion. The scattered illumination is less intense than the image itself. Consequently, if the image is weak, the scattered radiation may be negligible; otherwise, it is often of an intensity sufficient to influence the perceptual end result.

If the observer is facing a small disk target that is intermittently luminous, he will see the target flicker. But the flicker he sees will not be confined to the target portion of the field. There will be a very noticeable amount of flicker in the field surrounding the target, and this is attributed to the stray radiation (illumination) that reaches the retina around the target image. Stray illumination is significant in certain other situations as well.

LUMINANCE, RADIANCE, AND BRIGHTNESS

The peculiar relation between the energistic features of photic radiation (what we call familiarly "light"), the response of the visual system, and the ultimate response of the organism as a seeing person must be understood both to fully appreciate sight and to do basic work in visual perception. To begin with, we will abandon the term *light* as the name of the energy that effectively stimulates the eye. We will call it *photic radiation* and use the word "light" to indicate what one sees. There is no simple relation between amounts of photic radiation and the intensity of the visual experience we call *brightness*. Photic radiation is regarded as a wave phenomenon, composed of a combination of many wavelengths. The total of the combination is called a *spectrum*. Not all parts of the spectrum (not all wavelengths) are equally effective in producing brightness. Hence, the first step toward defining the relation of photic input to the eye and describing the ultimate sensory result is to determine the relative effectiveness of all parts of the spectrum.

One way is to select as a reference a wavelength or a very narrow band of wavelengths. Other wavelengths are then compared by using a bipartite

target in which one half is this reference source and the other is the wavelength or narrow band of wavelengths to be compared to it. The energy level of the comparison half of the target is adjusted until the two target halves look equally bright. This principle of comparison is continued until all parts of the spectrum have been examined, providing a set of measures of the relative amounts of energy for all parts of the spectrum that will produce equal brightness. The part of the spectrum requiring the least energy for producing the brightness involved in the comparison is taken as unity. All other parts of the spectrum, being less effective, are assigned various values all less than unity. Once this conversion to values has been made, a curve can be plotted, as in Fig. 4.1, called a *luminosity*

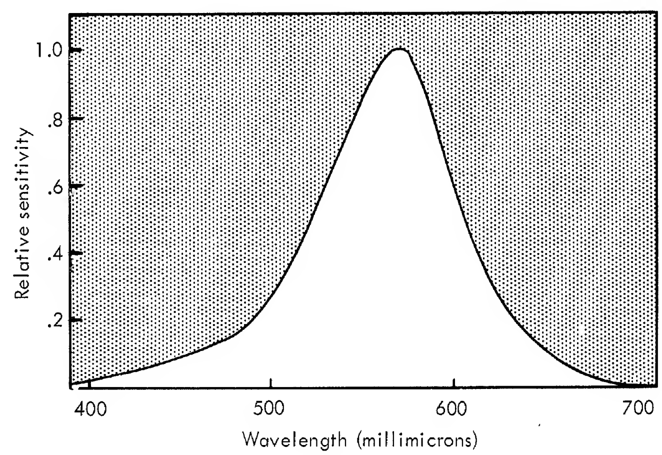


Fig. 4.1. Relative sensitivity of the human eye to various parts of the spectrum.

curve. Luminance is defined as the ability of photic radiation to produce brightness. It used to be called photometric brightness or simply brightness, but this confused the result with the cause, the input with the response.

Thus, we have mentioned photic radiation in purely energistic terms, called *radiance,* and in terms of its ability under standard conditions to produce brightness; this is called *luminance.* But this still does not tell the whole story, for seen brightness depends not only on photic energy per unit area applied to the retina but also on a number of other factors, such as state of adaptation of the eye, the amount of retinal area involved in the image, the shape of the target, and the input to other parts of the retina, as well as the part of the spectrum involved. The psychologist's or the psychophysicist's job is to determine by experiment what the various factors are and to what extent they determine brightness.

Conditions for obtaining luminance are made as simple and as fundamental as possible. The two halves of the bipartite target are of equal size

and shape. The duration of presentation is the same for both. Only a matching of brightness is required and this does not imply a measurement of absolute brightness but is simply a procedure for comparing various parts of the spectrum. Subjects with normal response (normal color vision) to all parts of the spectrum are used.

A step beyond designating *radiance*, *luminance*, and *brightness* can be taken, a procedure whereby a unit of brightness is chosen and the relation between a luminance scale and a brightness scale is ascertained. Brightness units have been called *brils* but brils have not yet come into wide use; their existence as theoretical and experimental achievement is important, however.

The unit of radiance is the *watt per steradian per square centimeter.* It is a little difficult to comprehend unless one works in photometry and is mentioned here only to indicate that photic radiation can be measured in *watts*, a familiar unit in the everyday measurement of electricity.

Luminance is measured in *candles per square foot* (or square meter or the like), or in *millilamberts* or certain other units.

PHOTOMETRY AND RADIOMETRY

There are two ways of measuring effectiveness of the photic impingement; one is photometry, the other radiometry. In general, *photometry* is a procedure in which a human observer makes instrumental comparisons between an established standard intensity and the stimulus whose intensity is to be determined. There are other procedures for measuring intensity, in which an instrument not involving human observation is acted upon by photic radiation and gives a quantitative reading. The "electric eye" or "photocell" is no doubt a familiar object; an application of the principle involved in the photocell can be used to measure photic radiation quantitatively. Photocells are somewhat selective in their sensitivity to the different wavelengths involved in ordinary photic radiation; some of them are very much like the eye in this respect, and for some purposes this is an advantage. For some other purposes, however, it is a disadvantage, as when we wish to know the total energy in the impingement or stimulus without regard to wavelength. Measuring photic impingements without the intervention of a human observer is known as *radiometry*, and the instruments used are called radiometers.

The photometer

You will have a much better idea of how photic radiation is usually measured if you understand the principle of the photometer. One of the most commonly used photometers is the Macbeth illuminometer (Fig. 4.2). It consists essentially in a photic source whose effectiveness upon the eye can be manipulated by varying its distance from the eye. The next

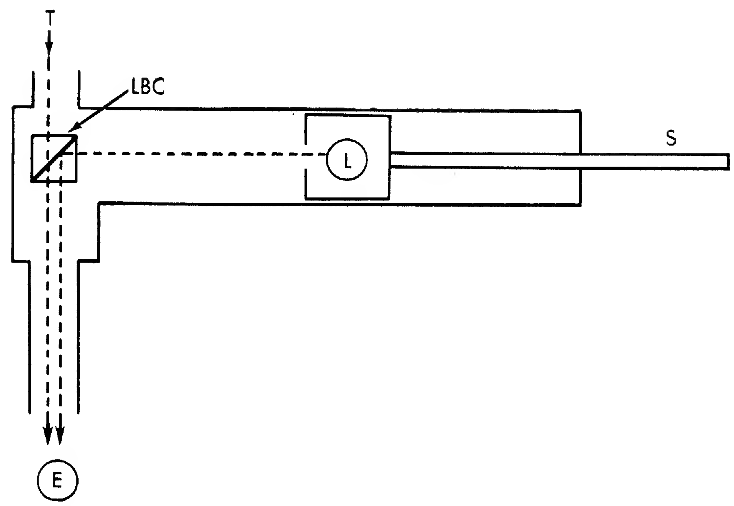


Fig. 4.2. Macbeth illuminometer, a very common photometer. S is a stick that moves L, the standard source of radiation with respect to the Lummer-Brodhun cube, LBC. T is the test source; E is the eye. The eye receives radiation from both the test source and the standard source.

essential element is a prism used to direct into the eye the radiation from both the source and the target to be measured. The prism (called a Lummer-Brodhun cube) is so constructed that the radiation from the instrument is visible as a ring, the radiation from the test target as a disk within the ring. The task of the user of the photometer is to adjust the intensity of radiation in the instrument so as to have the ring and disk match each other in brightness. The instrument is calibrated so that when the adjustment is made and the two fields match, the reading obtained can be transformed into any of the standard units for photic measurement.

When we want to know the value of illumination supplied to a working surface such as a desk, we place on the desk a disk of matte-white magnesium carbonate whose percentage of reflection is known (Fig. 4.3). The disk usually reflects back to the photometer about 70 percent of the radiation falling on it. Thus, when a reading is taken with the photometer pointed toward the disk, we know that the reading represents 70 percent of the radiation intensity falling on the disk. Thus the full intensity falling on the desk or table can be determined. If we pointed the photometer directly at the desk, we would not get the same reading, for the desk's percentage of reflectance is different from that of the disk and is unknown. Since we do not know what this percentage is, we would be unable to say what the level of illumination at the desk surface is. The procedure just described measures *illumination*, and a common unit is the *foot-candle*.

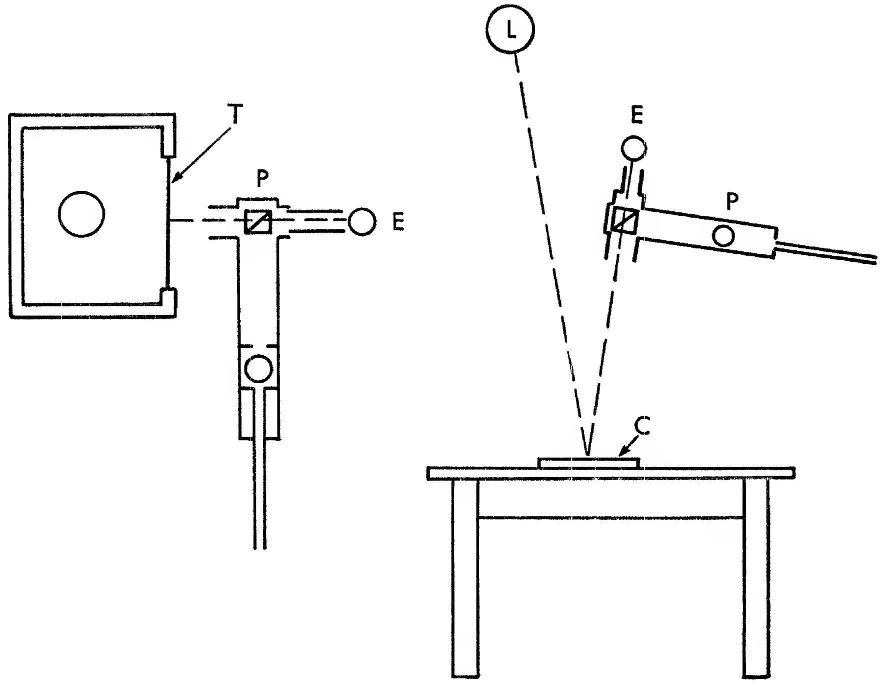


Fig. 4.3. The lefthand diagram shows that in measuring *brightness* the photometer P is pointed directly at the target surface T. The righthand diagram shows that in measuring *illumination* the photometer is pointed toward a calibrated reflectance surface C at a working surface such as a table. E indicates eye position.

When we want to know the luminance or the quantitative value of a target as viewed directly, we can point the photometer toward it and translate our reading into units that have to do with the effectiveness of the radiation as it directly strikes the eye. These are luminance units: *candles per square foot* (*or candles per square meter or square centimeter or square inch*) and *millilamberts.* Very often, the targets we look at directly are translucent opal-glass plates behind which there is some form of original photic source such as incandescent lamps.

The radiometer

Radiometers are instruments directly sensitive to photic radiation. Since radiation is made up of a number of different wave lengths, the question of whether the particular type of radiometer one uses or one needs is equally sensitive to all wavelengths in the spectrum is of prime importance. Of course, we remember from Fig. 4.1 that all parts of the human

eye are not equally sensitive to all parts of the spectrum. It will be noted that the central region of the band of wavelengths called the "visible spectrum" is the portion to which the eye is most sensitive.

Some radiometers—such as the exposure meters used by photographers in determining the proper camera settings for their pictures—possess sensitivity curves fairly close to the human luminosity curve. Some radiometers are sensitive in absolute energy terms.

SENSITIVITY RANGE

The range of intensities that the human eye is sensitive to is illustrated in Fig. 4.4. It will be noted that the range is enormous, covering about

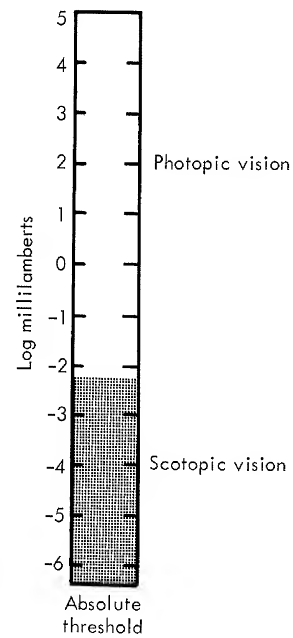


Fig. 4.4. The sensitivity range in human vision.

twelve logarithmic steps, which is to say from somewhere in the neighborhood of 0.000001 millilamberts to 10,000 millilamberts. This range is divided into two major portions, the lower consisting of the levels at which only the rods are sensitive (the scotopic range) and the upper consisting of the levels at which the cones are also sensitive (photopic range).

The figure can be labeled in several ways—in log millilamberts (throughout the whole range), in millimicrolamberts, microlamberts, and lamberts in accord with the levels at which these units are most appropriate. The very bottom of the range is the level representing the least energy that

will provide for any vision whatsoever; this point is called *absolute threshold.*

Psychophysical methods

Since the study of vision and certain other senses has been so largely a quantitative affair, certain methods specially suited to quantification have been developed and are called *psychophysical methods.* In general, they have to do with the relations between photic input and sensory end result. Various qualitative features of sensory processes can be dealt with quantitatively. Everyone understands that one substance can taste more salty than another, that one flower may be bluer than another, and so on. It is not generally recognized, however, that this is essentially quantification, and that experimentation has shown it can display considerable precision.

Psychophysical methods consist in standard ways of presenting the stimulus (including ways of varying its strength), standard ways of responding, and standard ways of treating the data. Since this book is not primarily concerned with experimental method, we will describe not the full list of experimental methods but a few of the more important ones.

In one method, the observer himself varies the impingement by doing something such as turning a knob to match a variable (comparison), with a standard alternately beginning each trial with the variable discernibly greater or less than the standard and then adjusting until the two items compared match. This is called the *method of average error* or the *method of adjustment.*

In another method, the experimenter varies the presentation up and down in intensity or some other property until the standard and comparison presentations match. The observer simply indicates when the experimenter is to stop during a single one-way variation. This is called the *method of limits.* In the method of average error, the data consist in a single set of readings to be averaged, but in the method of limits there are two sets of readings—one for the ascending trials and one for the descending trials. These may be averaged separately, and then the two averages can be averaged.

A third method is called the *method of constant stimuli.* The experimenter makes sufficient exploratory trials so as to gain a rough notion of the magnitude of presentations covering a range from chance to correct response in virtually all trials. Stimulus presentation in this method differs considerably from the two methods already described. Here two items are presented on each trial, one a standard, the other a comparison. Matching is not the task. Instead, the observer indicates whether the comparison is greater or less, in the characteristics under study, than the standard. This is the two-choice procedure. In a three-choice procedure, the response may be either "less than," "equal to," or "greater than." Generally, five or seven

variable items are chosen so as to fairly well represent this range. The standard or reference item lies in the middle of the range. The supposition underlying this technique is that the greater the physical difference between the standard and comparison items, the higher the percentage of correct responses.

Two curves are plotted as indicated in Fig. 4.5. With two choices, the observer could be correct half the time by guessing if an equal number of greater and lesser values of the comparison were presented in the test series.

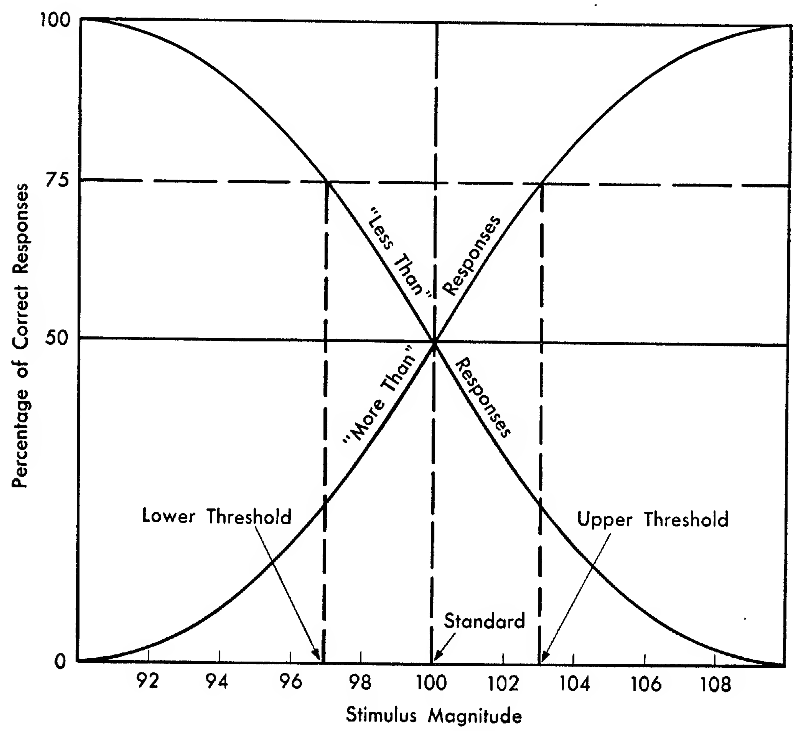


Fig. 4.5. The relation between percentage of correct responses and the difference between standard and comparison stimulus magnitudes. With two possible kinds of response, threshold is at 75 percent; with three kinds of response, three curves are involved and threshold is at 66.7 percent.

With three choices, guessing would result in one-third of the responses being correct. The threshold values are set accordingly. In each case, the threshold is the value halfway between chance correctness and correctness for every trial. Hence, the value that produces correct responses 75 percent of the time is considered to be the threshold in the two-choice procedure. In the three-choice procedure, the threshold value would be 66.7 percent. For further details see Fig. 4.6.

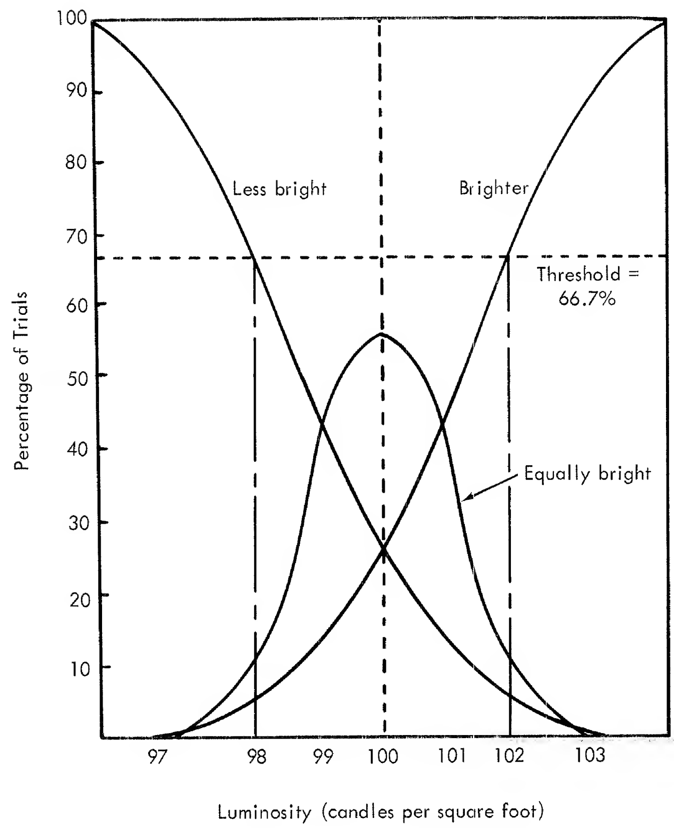


Fig. 4.6. The relation between the value of the stimulus variable (in relation to the standard) and the percentage probability of making a correct judgment when one of three responses is allowed. The responses in this case are "less than," "equal to," or "greater than" the standard. (S. H. Bartley. *Beginning experimental psychology*. New York: McGraw-Hill, 1950.)

Other psychophysical methods have also been invented. One is the *method of absolute judgment* in which no standard item is involved. The responder simply indicates on each trial whether the item is big, little, medium-sized, and so forth. This method has been variously modified and has been one of the forerunners of what today is called scaling.

Another more recent psychophysical technique is the *method of tracking*. It can be used on both man and animals and was invented by Békésy for auditory experiments. Like the others, it is a method for obtaining thresholds. For example, the observer listens to a tone and so long as he hears it he presses a key. When he no longer hears it, he releases the key. The experimenter gradually reduces the intensity of the acoustic impingement ("the stimulus"), and so the observer finally releases the key. As soon

as this happens, the instrumentation (or the circuit) automatically begins to increase the intensity of the impingement. Soon, the observer begins to press the key again. The arrangement can be automated so as to record the acoustic intensity at the points at which the key is released and pressed. This provides the data for calculating threshold. For animals—let us say pigeons (Blough, 1961)—this method can be used in a discrimination experiment: When the pigeon is trained to peck as long as one side of a bipartite target field is more intense than the other, intensity difference can be gradually reduced until pecking stops and increased until pecking begins again.

Measurement of thresholds

Over the years there have been many systematic descriptions of the relationship between target intensity and the response of the observer. The quantities measured have often been thresholds. There are, in general, two forms of threshold. One is obtained in vision when a luminous target of restricted visual angle is presented in a totally unilluminated room; the other form of threshold occurs when two portions of a luminous target are to be distinguished from each other in brightness.

To find the first form of threshold, the intensity of the target is raised from zero to a point that will just enable the observer to see something. Whatever he first detects, it will not be a uniform area with a sharp boundary. Rather, it will be a very, very faint, indistinct, blurred patch of light. It will be so dim that he will not be sure that it exists. In other words, he will see it only part of the time. To systematize the procedure, it is customary for the experimenter to present a number of exposures of the target, each exposure extending only for a brief time, generally a second or less. If the target is low enough in intensity it will never be seen, but if it is made progressively more intense it will be seen part of the time—that is to say, it will be seen in some of the exposures and not in others. As has already been indicated, the number of times a correct response can be made purely by guessing is taken into account in determining the value of the threshold.

When we deal with the emergence of some visible feature of a visual field on a totally dark background, we are dealing with *absolute thresholds*. It is as if we were occupied with something emerging out of nothing. Often this emergence is spoken of as emergence of a *figure* upon a *ground*. From this point on, we shall often use the terms figure and ground, or figure field and ground field.

The second sort of threshold often dealt with is the *differential threshold* (Fig. 4.7). It is measured by the value of the stimulus required for a figure to emerge upon a ground having an intensity value greater than zero. Sometimes ascertaining a differential threshold has to do with a small target

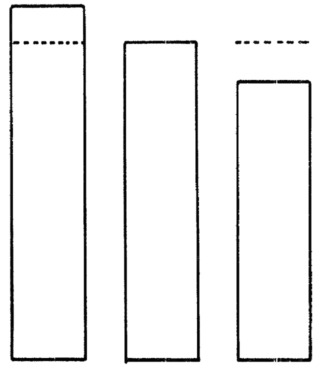


Fig. 4.7. Thresholds. The middle bar indicates the standard stimulus value, the left bar a comparison stimulus just perceptibly greater, the right bar a stimulus just perceptibly less than the standard.

on a homogeneous field. In that case, we deal with the threshold required for the target to stand out above the broad visual field as a whole. At other times we deal with a target of limited area that has two parts, one of which is more intense than the other, and our task is to determine how different in intensity these parts must be to be just perceptibly different. When we are concerned with *differences* in intensity between various portions of the target, we deal with *limens*. When we are concerned with the target *intensity* that just differs from the standard, we deal with *threshold* values. Figure 4.8 indicates this distinction.

From this point on, when we describe experiments and their results, it will be understood that in most cases the data obtained represent threshold

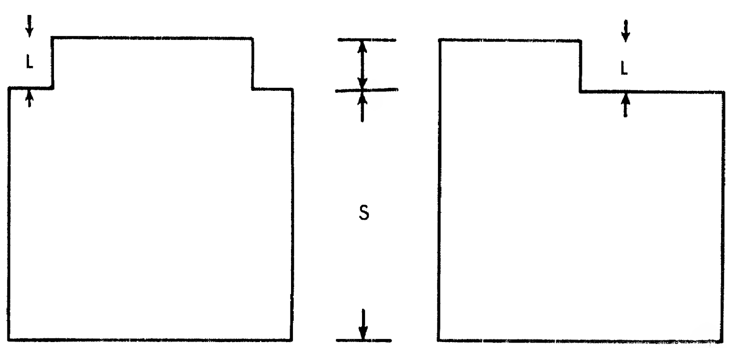


Fig. 4.8. Limens. S is the standard. L is the incremental value that makes the comparison stimulus just perceptibly different from S. This is the difference limen. The two parts of diagram illustrate the case in which a central target surface is more luminous than the peripheral and one half of the target is more luminous than the other.

values. Characteristically, in performing an experiment in adaptation or in brightness discrimination, we manipulate target conditions and obtain threshold values for each manipulation. Sometimes it is intensity alone that is varied, though at other times other properties are varied in a stepwise fashion. One can manipulate target *area*, for example, to find out whether targets subtending large visual angles have a different threshold from those subtending smaller visual angles. One can also manipulate the *duration* of target presentation; if the presentation time were cut down to a small fraction of a second, it might be expected that the target would have to be more intense to be readily perceived. *Shape* of target might also be a significant factor in determining threshold.

PHOTOSENSITIVE AND NEURAL ELEMENTS IN THE EYE

Findings in adaptation are understood in terms of the photoreceptor and other retinal processes underlying it. The receptors or sense cells in the human eye are of two sorts. The one, called *cones,* is sensitive to high, medium, and low-medium levels of photic radiation. The other, called *rods,* is sensitive not only to high levels but to very low levels. Each group of receptors has other distinguishing characteristics. For instance, the two kinds of cells are not equal in speed of reaction. The cones respond differently to various parts of the spectrum and form the basis of our ability to see various hues and saturations. Rods do not possess this property. But these elements alone do not account for the neural activity that is conducted from the eye to the brain. Part of the eye is a complex neural system involving convergence, divergence, inhibition, and other processes characteristic of masses of neural tissue.

The receptor layer (rods and cones) is the first layer of the retina's responsive tissue, the layer acted upon by photic radiation. The cells in this layer form the first in a chain of three (Fig. 4.9). The second type of cell in the chain is the *bipolar.* The third is the *ganglion.* The axons of ganglion cells are fibers that constitute the optic nerve. It will be noted from the figure that the axons of several receptors converge on a single bipolar cell, and the axons of several bipolar cells converge on a single ganglion cell. This means that there are more receptors than there are fibers in the optic nerve. All the neural processes that occur in the eye are not yet known, but it is certain that neural effects converge and diverge and that the overall temporal grouping of impulses sent up the optic nerve is a result of considerable interaction in the eye. The eye plays a role in determining many of the basic features of vision.

In addition to the elements mentioned, which form an ongoing chain, there are cells directed at right angles to this chain that participate somehow in the interactions just alluded to. Among these are the *horizontal*

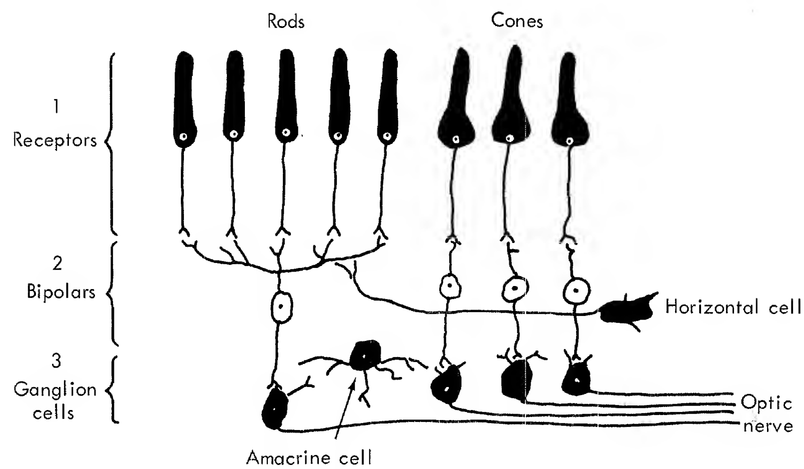


Fig. 4.9. Principle elements of the human retina. Layer 1 involves receptors, Layer 2 the bipolars, and Layer 3 the ganglion cells. These constitute the three-unit chain on the way to the lateral geniculate body and cortex.

cells and *amacrine cells*. There are still others, the functions of which have not traditionally been thought of as neural, but in regard to which more recent evidence seems to point toward active participation in forming the neural message conducted to the visual cortex.

LUMINOSITY CHARACTERISTICS FOR VARIOUS ANIMALS

Hecht (1921) determined the luminosity functions of two mollusks, the Mya and the Pholas, by determining the energies required for various parts of the spectrum to elicit a contraction of the animal's siphon with a constant latent period. Latency of response in these animals is relatively long and was easily measured. Mya displayed maximal sensitivity to a wavelength of about 500 millimicrons. The Pholas' maximum was about 570 millimicrons.

Later, R. H. Brown (1936, 1937) measured the rabbit's luminosity function, using a breathing criterion. He conditioned the animals by coupling a photic pulse with an electric shock that produced a breathing effect. He was then able to determine the minimal energy at each part of the spectrum that would evoke the conditioned breathing reaction. He did this for scotopic and photopic levels, which produced different maxima. The scotopic curve displayed a maximum at 510 millimicrons, photopic at about 550 millimicrons.

Still later, Hecht and Pirenne (1940) mapped the luminosity curve for the owl because it is supposed that owls see exceptionally well at night,

under low illumination. They found that the owl's scotopic luminosity curve similates the usual rod curve and is not different in the ways suspected.

Still more recently, Blough (1957) studied the luminosity function in the pigeon through an instrumental conditioning process. The bird pecked on key A when the target was visible and on another key B when it was not visible. The pecks regulated the intensity of the target by activating a mechanism that controlled target intensity. Pecking on A gradually reduced intensity to zero. Pecking on B provided food on a certain percentage of trials if the target was "dark." As a result of the experimental arrangement, the pigeon kept alternating the impingement value above and below absolute threshold. The pigeon's maximum for scotopic curve was found to be about 500 millimicrons. The curve resembled the luminosity curve for an aphakic human subject. (Aphakia is the condition in the human eye when the lens has been removed, as in a cataract operation.)

THE DUPLICITY THEORY

The duplicity theory, proposed by Schultze (1886), by Von Kries (1895), and then by Parinaud (1898), details the roles played by the rods and the cones and indicates how they differ and account for a number of wellknown features of visual sensation. The different activities of the two kinds of receptors is reflected in the quantitative characteristics of many visual end results. At high luminances cones provide for both color vision and seeing fine details (high visual acuity). Rods, acting at lower luminances, provide for vision without color.

Two different variables figure mainly in differentiating between rod and cone function. We have already mentioned luminance; the other is retinal position. It is known that the retinal distribution of the rods and cones differ. The cones alone populate the very central area of the retina, the fovea (a circular patch subtending about 1.5° in the human eye). As areas progressively further from the fovea are reached, the density of distribution of cones tapers off rapidly for the first 10°. From there on, the density is almost uniform but is much lower than the population density of the rods. The rods, on the other hand, begin only at the border of the fovea and from there rise in population, so that from there outward there are many more rods per unit area than cones. Outward from about 10° the rod population density is nearly constant. Thus, if the experimenter wants to study cone function, he uses targets whose images lie only in the fovea. If he wants to study rods and cones, he can move outward. If he wants to study rod function, he can use low luminances. Many manipulations on such bases have been made over the past nine decades, and from the results the characteristics of rod and cone function have been disclosed.

There are five major visual functions among those that display dif-

ferences between rod and cone function. The first is adaptation, by the work of Hecht, Haig, and Chase (1937). The next is intensity discrimination in the work of Steinhardt (1936). The third is differences in critical flicker frequency (CFF) as demonstrated by Hecht and Verrijp (1933). The fourth and fifth functions are color vision and visual acuity. Color vision will be discussed in Chapter Five. Visual acuity was shown in Fig. 3.7 from the results of Shlaer (1937); it will be noted that visual acuity, like other functions, presents a curve with two portions, one representing rod function (at low levels of illumination) and the other representing cone function (at high levels of illumination).

ADAPTATION

Dark adaptation

The rate of dark adaptation depends upon the level of adaptation from which the dark adaptation starts; this is called the preadaptation level. Winsor and Clark (1936) showed that rod adaptation for a high preadaptation luminance was slower than for lower levels of preadaptation. Hecht, Haig, and Chase (1937) showed that both the rod and cone components of adaptation become more and more delayed as preadaptation luminances are increased (Fig. 4.10). Wald and Clark (1937) showed that the dura-

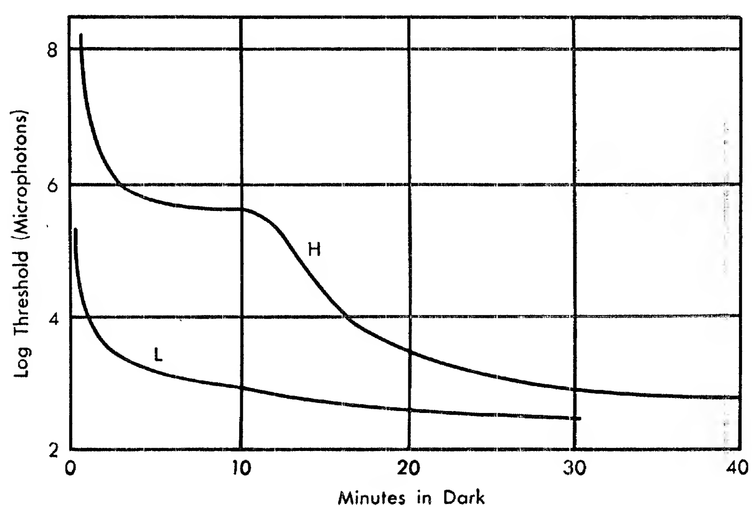


Fig. 4.10. Dark-adaptation curves. H is the course of dark adaptation starting from a preadapting intensity of 400,000 trolands. L starts from 263 trolands. (S. Hecht, C. Haig, & A. M. Chase. The influence of light adaptation on subsequent dark adaptation of the eye. *J. gen. Physiol.*, 1937, **20**, 831–850, Fig. 2.)

tion of the preadaptation state also affected the rate of dark adaptation. The longer the preadaptation takes (at least up to 10 minutes, let us say), the more delayed the dark adaptation is. Mote and Riopelle (1953) and others have obtained similar results. Wald (1954) explained these results on a photochemical basis, the description of which is too involved for presentation here.

When an eye is adapted to a high intensity (or luminance), it can detect targets most readily when the fovea is stimulated. That is, the fovea requires less illumination than the periphery does. On the other hand, the fovea is much less sensitive than the periphery when the eye is completely dark adapted. Consequently, the amounts of dark adaptation for the periphery will manifest wider ranges than for the fovea.

Brown, Graham, Leibowitz, and Ranken (1953) followed the course of dark adaptation for a visual acuity target. They used the regular dark-adaptation testing procedure, but the test target used at various intervals during nonillumination of the eye was an acuity grating, an alternating series of stripes that under required conditions look dark and light. Of course, in visual acuity experiments, the fineness of the stripes (the visual angles subtended by them) is a variable, and so, in the type of investigation described level of visual acuity is an arbitrary matter. The width of the stripes, for example, could be set for a visual acuity of 0.5 or it could be set for a visual acuity of 0.25, and then dark adaptation could be carried out until the striped nature of the target became visible. Brown and his colleagues found that, with wide grating stripes, resolution was possible through the rods, but with fine stripes only the cone portion of the retina was effective. In general, the higher the visual acuity criterion is, the higher the luminance must be for successful seeing of detail, but this luminance is also a function of time allowed for dark adaptation.

When dark adaptation is tested in a neurophysiological preparation such as the eye of the Limulus (the horseshoe crab), the record is of numbers of impulses discharged by the single visual receptor unit. It discharges more and more impulses as the unit is tested after longer and longer intervals without illumination. For example, at 30 seconds, let us say that four impulses are discharged, at 5 minutes nine impulses, at 10 minutes thirteen impulses, and at one hour twenty-seven impulses (Hartline and McDonald, 1947).

Light adaptation

Baker (1949) ascertained the threshold increment in luminance (L) for a 1° foveal target presented for 20 milliseconds obtained at various times over a period of 15 minutes. He began with observers who had been without photic stimulation ("in darkness") for 10 minutes. Light adaptation was so rapid during the first 3 or 4 seconds that he could not measure

it by this method. He measured subsequent changes, which in comparison with the first adaptation were small. The pattern of changes was characteristically as follows, regarding light adaptation as depression in sensitivity. After the primary depression, there is a rapid recovery that gradually decelerates, reaching a new peak at 2 to 3 minutes after onset. From then on, sensitivity changes slightly to a final level at 10 to 15 minutes.

This is to say, then, that exposure to photic radiation following dark adaptation does not produce a simple effect described as quickly reducing sensitivity to the level suitable for the eye to function in an illuminated environment. The effect is complex. Baker's procedure was to measure the way in which the threshold increment in photic intensity (I) varies in a dark-adapted person during exposure to an adapting illumination, the target. The results are not comparable to those using the older methods because they used different measures of sensitivity.

Lohmann (1906–1907) made the classical measurements of light adaptation. He used the absolute threshold to indicate visual sensitivity and thus the amount of light adaptation. His curves show a continuous rise in sensitivity, that is, a simple effect in contrast to the complex effect obtained by Baker.

INTENSITY DISCRIMINATION

Stimulus variables at threshold

Brightness depends on a number of factors, among which are area of the retinal image, luminance, and impingement duration. Classically, each was studied one at a time with the others held constant. But added understanding of visual mechanisms is to be gained by determining how two or more factors vary in relation to each other in producing a constant end result, often taken to be threshold brightness. Some earlier workers were concerned with relations between target area and photic intensity to produce threshold brightness.

Riccò (1877) found that the product of area and intensity (or luminance) is constant for threshold excitation. This has been called *Riccò's law* and holds when the image of the target covers the fovea and also in the periphery if the image subtends an angle no greater than 10 minutes. Piper (1903) stated a rule also, which says that in peripheral vision the product of intensity and the square root of the area is a constant for threshold. *Piper's law* has been found to hold in the periphery for visual angles lying between 2° and 7°.

Much more recently, Graham, Brown, and Mote (1939) extended the examination of the retinal arc-luminance relations to cover greater visual angles. They believed they could control the experimental conditions more precisely than earlier workers had. For targets involving visual angles

of from 1.86 minutes to 1° for the fovea, and from 1.86 minutes to 25°, the results were as follows: When the logarithm of luminosity is plotted against the logarithm of the target radius, the curves for both fovea and periphery are nonlinear but increase in slope as area is increased. The increase is consistent and becomes asymptotic for the largest areas.

Bloch (1885) suggested that for short photic pulses the sensory effect depends upon the product of luminance and pulse duration. This is known as *Bloch's law* and results have been confirmed for threshold sensation for durations exceeding one millisecond. Blondel and Rey (1911) showed this for peripheral stimuli, and Karn (1936) for the fovea. What happened with pulses briefer than one millisecond was left in doubt. Brindley (1952) reduced his photic inputs to about 4×10^{-7} seconds and found a satisfactory reciprocity between luminance and duration for suprathreshold effects. It is supposed that this would hold for threshold as well.

Brightness discrimination and target diameter

Figure 4.11 (Steinhardt, 1936) shows a number of curves, each of which represents the relation between $\Delta I/I$ and level of retinal illumination (both in logarithmic terms) for a given target size (disk). The diameters of the disks vary from 23.5 minutes of arc to 24°. That would be roughly a range of from one to 60. The largest target would have sixty times as great a diameter as the smaller one. All the disks were looked at directly; hence their images were centered on the fovea. When the smallest three targets were used, their images fell fully within the fovea. When the succeeding targets were used, they included retinal areas farther and farther from the fovea and thus activated many rods.

Brightness contrast and induction

While the effects of stimulating separate areas on the retina can be determined, there are many situations in which the level or areal extent of stimulation of adjacent areas has a very marked effect on the observed brightness of the area in question. Contrast not only has to do with brightness but also pertains to color effects. This is to say there are both *brightness contrast* and *color contrast*. We shall concern ourselves only with brightness contrast here.

In dealing with contrast as with other phenomena, we should be careful to distinguish between the phenomena themselves and the conditions that produce them. For example, contrast is a perceptual phenomenon and the factors that are manipulated should not have "contrast" for a label. If one is concerned with differences in intensity between the impingements on two portions of the retina, the difference can merely be called a difference or a ratio, thus retaining the term "contrast" for what is seen.

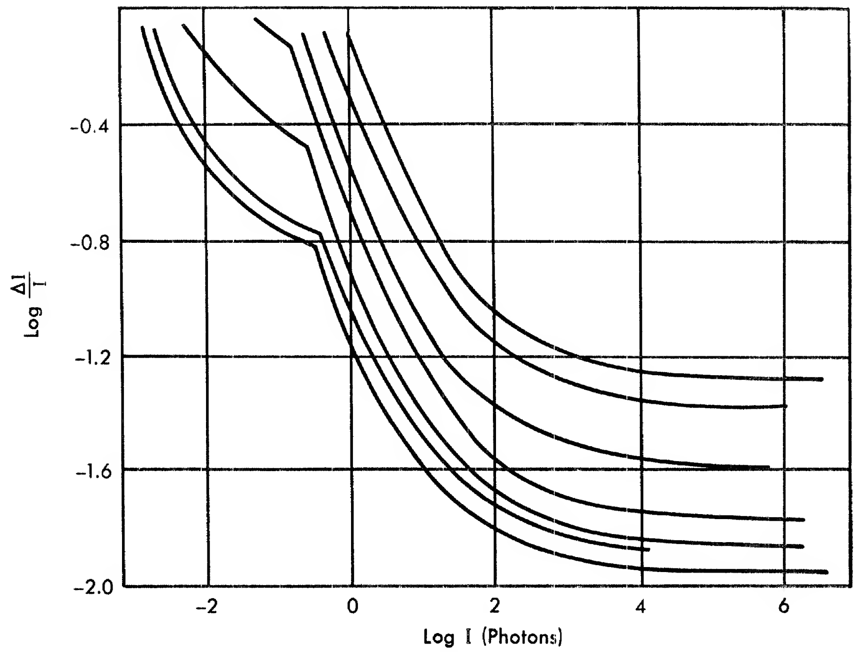


Fig. 4.11. Human intensity discrimination as dependent upon illumination and size of target. Each curve is for a separate target; the visual angles subtended are as follows, reading from the upper to the lower curves in order: 23.5′, 31′, 56′, 2° 14′, 5° 36′, and 24°. (J. Steinhardt. Intensity discrimination in the human eye. I. The relation of Δ I/I to intensity, *J. gen. Physiol.*, 1936, **20**, 185–209, Fig. 2.)

Purdy (1935) pointed out that in general the brightness of any visual area is lowered by raising the brightness of nearby areas. He continued by indicating that a small area of medium photic intensity may appear white when its surround is totally unstimulated. If the surround is progressively supplied with increasing intensities of illumination, the brightness of the small area is progressively reduced. With sufficiently intensely stimulated surrounds, the original white may even be changed to black.

Hess and Pretori (1894) made one of the earliest psychophysical investigations of brightness contrast. They used a test field of a 1° square centered on a 10° inducing field. The match field was also a 1° square centered on an adjacent 10° field, all of which was viewed with one eye. The luminance of the match field needed to equate with the test field was found to decrease with increasing luminance of the inducing field. The possibility of complex interactions between the four fields was so great as to make inferences quite uncertain.

One simpler procedure for measuring brightness contrast is to use three

target components A, B, and C. A and B are to be matched; A is the standard, B the comparison field. If C is placed adjacent to the standard A, a shift in the comparison intensity will be required for A and B to match. Thus, when the order of the components in the visual field is CAB, C affects A. Thus, for A and B to match, B has to be changed in intensity and that change is measured.

Diamond (1953) found that if C, the inducing target component, is raised in intensity so that its brightness is greater than A, then A has to be raised if the original match between A and B is to be maintained. That is, Diamond started out with A and B equal in brightness. Then C, which was next to A, was introduced and raised in intensity until it appeared brighter than A. The result was that B now appeared brighter than A, so A had to be raised in intensity to restore the match between A and B in brightness. The amount by which A had to be increased in intensity was the measure of the inducing effect of C.

In 1955, Diamond studied the effect of area of the inducing target upon the required luminosity of the test field to make it and the match target appear equally bright. His test target was a rectangle. The inducing target was equal in length to the test target but could be made narrower or wider than the test field. The match target was somewhat farther away from the test target than the test target's length. Actually, the image of the test target was placed on the opposite eye, and the posture of the two eyes was controlled by a fused fixation point. As it was increased from its narrowest value to its widest, there was a concomitant decrease in the luminance needed for equal brightness of the test and match targets. The amount of the decrease in luminance needed increased with increases in the luminance of the inducing target.

Alpern and David (1959) used four rectangular inducing fields, placed two on each side of the test field. Either two or all four of the inducing targets were used at a time. The match target image was placed on the retina of the opposite eye. They found that the inducing luminances needed for the brightness equation was less with all four of the inducing targets than the sum of the independent measures of two inducing targets at a time. This discrepancy increased as luminance of the inducing targets was decreased and as the separation of the inducing targets from the test target was increased. Alpern (1953) offered some evidence to indicate that inducing targets in the retinal periphery result in a greater contrast effect than those at the center.

Spatial inhibition in the Limulus eye

Neurophysiologists have provided some information about visual mechanisms that seems to be quite relevant here. For many years they have been studying the responses of the elements of the compound eye of the horse-

shoe crab (Limulus) to controlled photic stimulation. The Limulus eye is made up of a number of units called ommatidia. Each ommatidium is composed of more than one cell but forms a functional unit whose activity can be recorded separately from the activities of other ommatidia. The compound eye is populated by ommatidia lying side by side and the aim of the investigators has largely been to determine how adjacent ommatidia, and even those somewhat separated from each other, affect one another. Separate ommatidia can be stimulated independently by tiny point-like patches of radiation. This is of quite distinct advantage, for in the vertebrate eye the receptor units synapse with the bipolar cells, and these, in turn, with the ganglion cells, before a successful recording site is reached. Hence, in the vertebrate eye, certain complex interaction processes occur before recording can be accomplished.

In the Limulus, then, the activity of single ommatidia or combinations of them can be studied. It has been found that the activity (or rate of discharge of impulses) of an ommatidium is reduced when adjacent ommatidia are activated. This is of course called inhibition. The activity of the adjacent ommatidia also raises the threshold and reduces the number of impulses discharged when a brief photic pulse is used as the stimulus.

The magnitude of the inhibition, indicated by the decrease in discharge frequency, depends on intensity, area, and configuration of the illumination surrounding the test ommatidium. This was shown by Hartline, Wagner, and Ratliff (1956). Hartline and Ratliff (1958) showed that the inhibitory effects from different ommatidia combine with one another. Thus it can be said that inhibition summates. Furthermore, it has been shown that the threshold of inhibitory influence increases with distance between the ommatidium involved.

Disinhibition

Another result, called disinhibition, has been demonstrated. When a spot of photic stimulation activates one ommatidium and then a second spot activates a second ommatidium, the activity of the second ommatidium inhibits the activity of the first one—that is, it slows down its discharge. A third spot of photic stimulation can be used to activate a third ommatidium, which is far enough away from ommatidium number one not to affect it greatly but is near enough to ommatidium number two to influence it. The influence consists in a release of number one from some of the initial effect of number two upon it. While various complex interactions occur in the Limulus eye, none of them happen to be facilitory. All are inhibitory in one way or another.

The stimulus manipulations made in the disinhibition investigation are reminiscent of those made in the brightness contrast investigation of Diamond (1953, 1955). When Diamond performed his induction experi-

ments, the work of Hartline and Ratliff (1957) had not yet been performed and the concept of disinhibition had not been coined. While the perceptual (or sensory) effects were clear, the nature of a possible mechanism had not been disclosed.

Disinhibition in the human eye

The neurophysiological work on disinhibition induced Mackavey, Bartley, and Casella (1962) to perform human experiments to test for disinhibition. They used the following target arrangement. The match target was imaged on the left retina. The test and the inducing targets were imaged on the right retina. Using the match or standard target in a separate eye removed it from any stray photic effects from the other targets while still keeping it a standard reference for brightness. The inducing target was placed at five different distances from the test target, ranging from 1° to 5°. It was shown that the presence of the inducing target affected the luminance of the test target needed to equate it in brightness with the match target and that this effect was lessened as the inducing target was moved farther away from the test target. The effect became asymptotic at about 4° or 5°. The results seemed quite similar to the Hartline and Ratliff effects in the Limulus. The neural mechanism for the sensory effects is very probably in the retina, although it could have been further along in the optic pathway.

INTERMITTENT STIMULATION

Temporal limitations and special temporal conditions of stimulation are significant in the analysis of brightness discrimination. They consist in (1) variation in duration of single photic pulses, (2) presentation of pairs of pulses whose temporal separation is varied, (3) single trains of pulses containing various numbers of pulses and various temporal separations between the pulses in the trains, and (4) series of trains of pulses with the separation between trains in the series being varied. Of course, in this case, the variables already mentioned in (3) are included. Most studies in this kind of experimentation are called flicker experiments or intermittent stimulation.

Whereas the eye is usually supplied with uniform radiation that continues for some time, it is sometimes presented with a series of short pulses. When the pulse rate is low enough, the observer sees a succession of alternations between light and dark. When the rate is increased, the result is called flicker. Experiments with intermittent stimulation are, therefore, often called flicker experiments.

The first end result of significance to us is that when the photic pulse rate is made sufficiently high, the human observer ceases to see flicker or any sort of fluctuation whatever. The point at which the light seen becomes

perfectly steady is called the *fusion point*. The pulse rate at the fusion point is called the *critical flicker frequency*, or CFF. Most of the study of intermittent stimulation over the past century has concerned the conditions having to do with CFF.

In addition to pulse rate itself, several other factors—such as stimulus *intensity*, the *part of the spectrum* used, the retina *area* covered, and the position of the image on the retina—have been studied. Figure 4.12 indi-

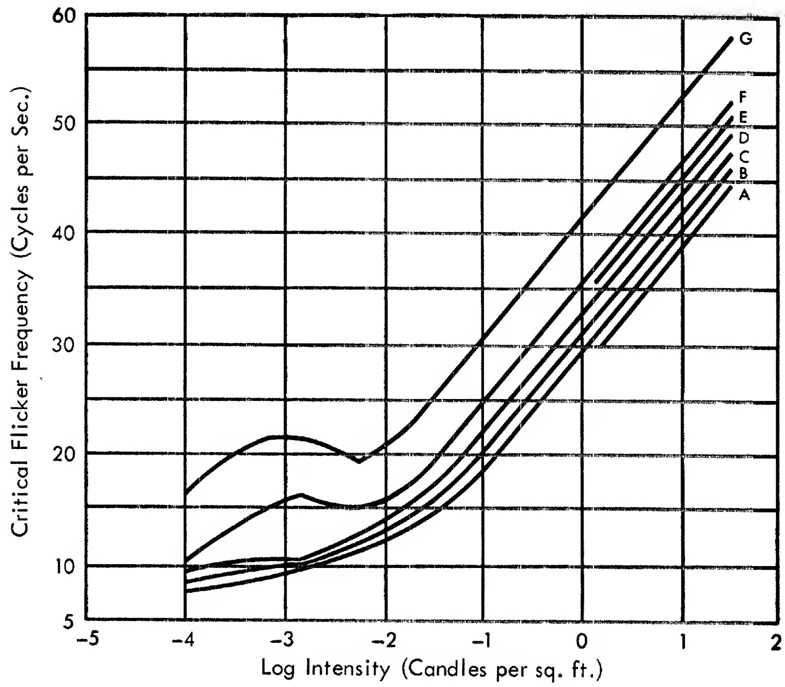


Fig. 4.12. Relations between target area, intensity, and critical flicker frequency. Each curve is for a target of different angular subtense. A is 51′, B 1° 18′, C 1° 50′, D 2° 44′, E 3° 42′, F 5° 6′, and G 31° 51′. The stimulus and no-stimulus phases of the cycle are equal. (S. H. Bartley & J. L. Seibel. A further study of entoptic stray light. *J. Psychol.*, 1954, 38, 313–319, Fig. 1.)

cates the general relation between stimulus intensity, stimulus area, and CFF. The horizontal axis represents stimulus intensity in logarithmic units. Each curve is for a separate stimulus area, and the values are given in degrees of visual angle (angles of arc on the retina). It will be seen that as area is increased CFF rises for most intensities. When intensities are extremely low, only the rods are activated, and the results differ from when cones are also involved. The curves flatten out and a different set of CFFs result as intensity is varied. That is, CFF is not always changed as much or

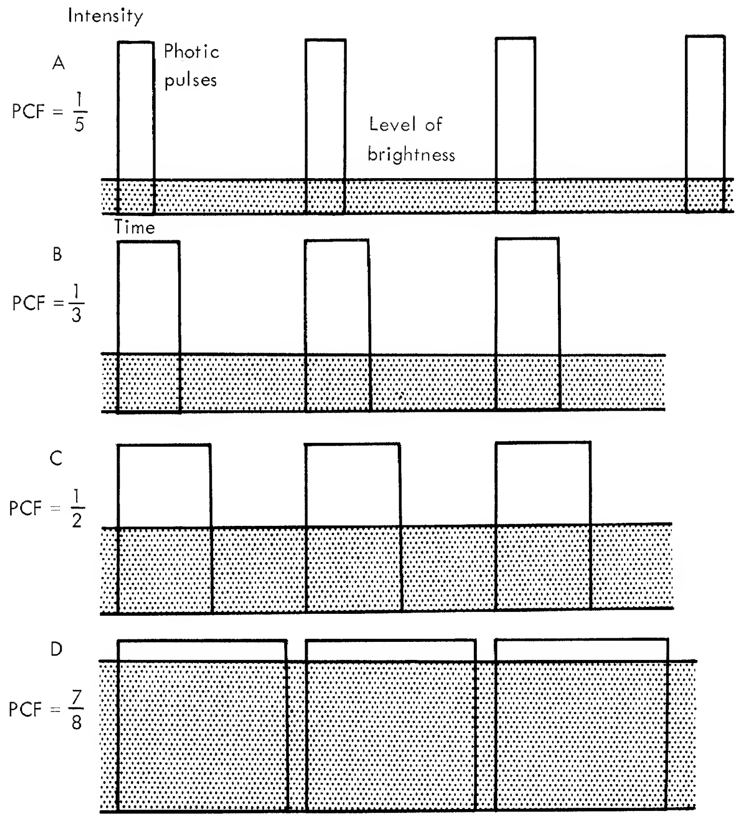


Fig. 4.13. Relationship between the pulse-to-cycle fraction and brightness produced when intermittency is sufficient to produce steady light. In A only 1/5 of the cycle is occupied by photic pulse; hence, the seen brightness is 1/5 of what it would have been with steady illumination. In B, C, and D, the pulse-to-cycle fractions (PCF's) are 1/3, 1/2, and 7/8, respectively. The relationship is Talbot's law.

in the same direction as when the cone portion of the intensity range is involved. Thus, we find that the events in the eye itself are crucial in determining the perceptual outcome. Critical flicker frequency is also manipulated by using different parts of the spectrum.

More than one hundred years ago, Talbot (1834), the father of modern photography, found that there was a simple, fixed, thoroughly dependable relation between brightness that an observer sees and the fraction of the cycles of intermittency occupied by the pulse. Let us say, for example, that the photic pulse itself occupies as much time as the interval between pulses. This gives a one-to-one ratio (50 percent to 50 percent). Talbot found that the light looked half as bright as it would look if the stimula-

tion were the same intensity and continued throughout the cycle, that is, if it were produced by steady stimulation. He stated that with intermittent stimulation the perception of steady light produced is as bright as it would be were the same total stimulation distributed evenly throughout the cycle. This is known as *Talbot's law* (Fig. 4.13). Accordingly, if the stimulus part is one-third of the cycle, the brightness will be one-third as great as if the same stimulus were continued throughout the whole cycle. If an experimenter wants to reduce the effective intensity of a target by any amount, he can do so by interrupting the light source with a rotating open-sectored disk with an appropriate ratio of blade to open sector.

Brightness enhancement

The study of the perceptual outcomes from the use of intermittent stimulation has not been wholly confined to pulse rates at and above the fusion point. When pulse rate is very low, the visual result is of course an alternation between light and dark periods. As pulse rate is increased, the dark period disappears and becomes merely a period less light than the original light period. As pulse rate is further increased, the visual result may be described as a light field (a steady component) and a superimposed fluctuating component. As pulse rate is increased still further, the fluctuating component becomes less amplitudinous and less conspicuous until finally it disappears, leaving only the steady field (Fig. 4.14).

With pulse rates failing to produce steady light—that is, with subfusional pulse rates—the effectiveness of intermittent stimulation as photic pulse rate is progressively reduced varies from the Talbot level to levels even greater than for steady stimulation. The curve in Fig. 4.15 representing the effectiveness of intermittent stimulation rises as pulse frequency is reduced. Finally, the curve reaches the point at which steady and intermittent stimulation are the same, shown where the ascending curve reaches the horizontal line in the graph. The increased effectiveness of intermittent stimulation over that of steady stimulation is called *brightness enhancement*.

The principle of enhancement was demonstrated by Brewster (1834) and by Brücke (1864), who used a revolving disk with white and black sectors (Fig. 4.16). A small solid white disk was placed on another disk. When certain rates of revolution were used, the glitter of the white sectors rose above the brightness of the white of the small disk. Nowadays, the enhancement phenomenon is also called the Brücke-Bartley effect.

Brightness enhancement, then, is a term referring to the increase in brightness that results from an intermittent stimulation. It is known that other kinds of stimulation produce unexpected levels of brightness and, while they may be called examples of brightness enhancement as far as the dictionary definition of enhancement is concerned, calling them so has

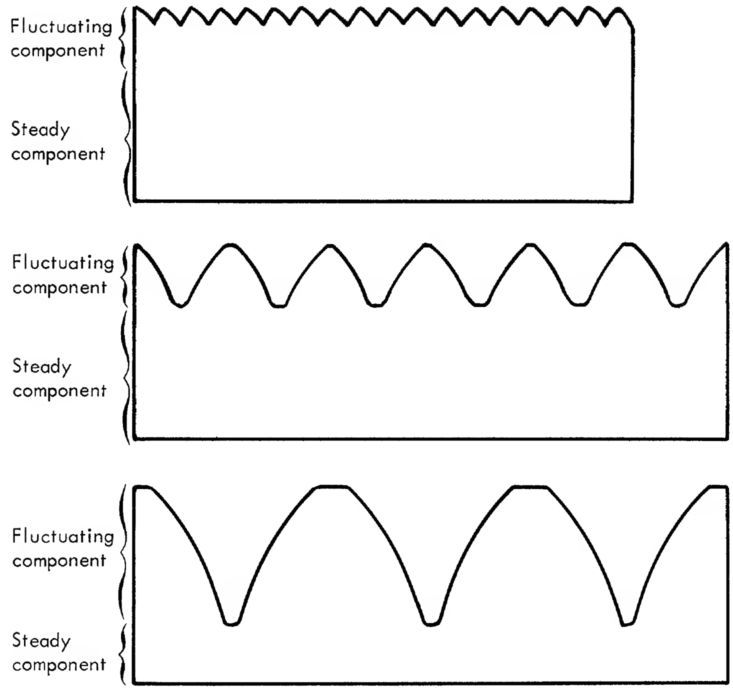


Fig. 4.14. Relation between the two fluctuating and steady components of a flickering field and intermittency frequency. As rate increases, the steady component increases and the fluctuating component becomes less and less. Throughout a certain range of frequencies, the steady component is so predominant as to allow comparison of brightness between the target and a steady one.

already given rise to unfortunate confusion between the examples. This is particularly true in discussions attempting to explain the mechanism underlying increases in brightness. In the present discussion of brightness increases, brightness enhancement refers only to the results accruing from intermittent stimulation within the rate range producing a steady component that can be matched with a steady target.

Brightness enhancement was a result obtained when the rate of intermittent stimulation was high enough to enable the perceiver to see an "average" illumination. By the time the rate is reduced from CFF to 10 pulses per second, a considerable steady component of brightness is still involved. The fluctuating (flickering) component is only slight. However, when rates are reduced much farther, flicker begins to predominate. Thus, what the observer sees as intermittency rate becomes an alternation of light and dark (flashes and dark intervals), an entirely new visual phenomenon. He is no longer able to make a simple comparison with the steady field of the comparison target.

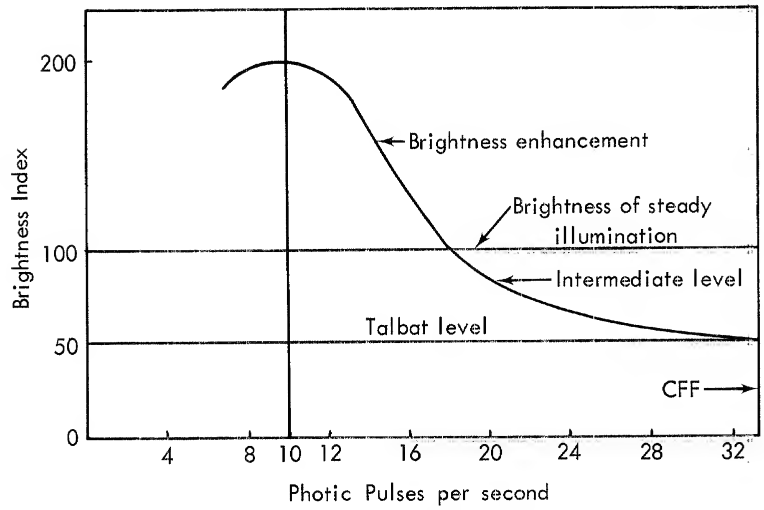


Fig. 4.15. Relation between brightness enhancement and the number of photic pulses delivered per second. At a high rate of intermittency that produces the appearance of a steady light, Talbot's law operates and brightness is at the Talbot level. As rate is decreased, brightness begins to exceed the Talbot level and eventually becomes equal to the brightness produced by steady illumination. As rate is further decreased, brightness transcends the level produced by steady illumination and is called brightness enhancement.

If perchance he is able to select out the brightness of the bright phase in the alternation, he cannot be considered as making a strict continuation of what he was doing when the major brightness component of the target was steady. Thus, if he finds that these rates provide for brightnesses greater than that obtained at higher rates, he moves outside the scope of the definition of brightness enhancement.

Brightness increase is also produced by single, short, isolated photic pulses. If one compares the effect of a short pulse to that of continuous radiation of the same intensity, he will find that the pulse effect, the flash, is the brighter. Accordingly, this is technically speaking not to be labeled brightness enhancement.

Neural mechanism for brightness enhancement

Brightness enhancement—the greater brightness produced by intermittent stimulation rather than by steady stimulation—is somewhat paradoxical. It appears to be a case of obtaining more output from less input. We have a good example from which to determine the underlying body mechanism and provide an explanation of and solution to the puzzle.

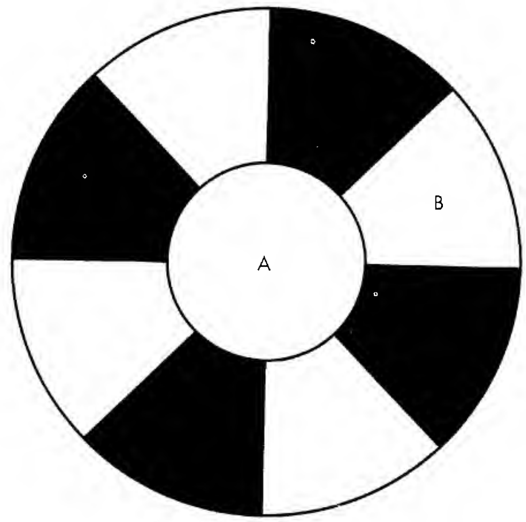


Fig. 4.16. Components of a Brücke disk. The inner component A is highly reflective, giving the appearance of whiteness. The outer segment B consists of alternate light and dark sectors. When the disk is revolved at a certain rate range, B begins to look brighter than the A.

There seems to be a very satisfactory solution. A full exposition would be quite lengthy and complicated, but a short summary can be given here.

Bartley (1939, 1941) demonstrated in neurophysiological experiments that the channels of the optic pathway can be activated in various temporal groupings. By channels is meant individual circuits from eye to brain. They consist in certain complex chains of neurons in the eye, each of which feeds into a single fiber in the optic nerve and then into a complex circuit in the brain. There are myriads of them all lying parallel to each other. An intense and brief photic stimulus will activate many or all simultaneously. Once activated, they require a certain amount of time to recover before being activatable again. An extended photic stimulus will not hold all the channels into synchrony but will work toward activating the channel population into activity uniform throughout the time the visual system is responding. Hence, at no time except at the first instant will the photic input succeed in producing the sensation of a brightness as great as that produced by a brief photic pulse. The complete description of the relation between types of photic input and channel activity, based upon a number of neurophysiological and psychophysical studies, is known as the *alternation of response theory.*

SUMMARY

The present chapter was divided into three parts: general considerations, studies in adaptation and brightness, and flicker and flash.

The first part included illustrations of adaptation and brightness in everyday life. In general, it was given over to explaining how photic radiation (or "light") is measured and to a description of the sensitivity characteristics of various animals. It explained the difference between luminance, radiance, and brightness and explained the mechanisms of photometry and radiometry.

The second part included experimental studies of dark and light adaptation, impingement variables at threshold, brightness discrimination and target diameter, brightness as dependent upon contour processes, brightness contrast and induction, spatial inhibition in Limulus, and disinhibition in both animals and man.

The third part dealt with intermittent photic inputs and some of their sensory consequences, and it introduced the alternation of response theory to account for data in this area.

FIVE

Perception of Color

Throughout our discussion we have abandoned the copy theory of human perception and have put in its place the idea that certain complex energy patterns impinging on the sense organs induce certain kinds of organismic reactions, one aspect of which is our experiences. We have supposed that our experiences are perfectly unique products of the human organism and copy nothing in the universe.

Nowhere else in all the study of perception is it more necessary to maintain our understanding of the noncopy relations between organisms and environment than in dealing with color experience. The study of the perception of color is a great deal more than dealing with wavelengths in the spectrum of the illuminant, be it sun or incandescent lamp or any other source. The colors we see are in every case a complex end result of several factors: the composition of the illuminant or illuminants, the several reflectances of the visual targets, their spatial relations to each other, the reflectance of the surround or ground, the state of adaptation of the eye, and the body processes, including the activity the organism as a person is carrying on at a given time. Under fundamental and strictly controlled conditions reduced for study in the laboratory, the learning that one observer versus another has undergone does not perhaps crucially enter in, but under everyday conditions it does.

Let us take a look at some examples of color phenomena to see what they are like and what it is that has to be dealt with. The following are some commonplace situations in which color is seen and is of some interest.

1. Food is less palatable under some illuminations than under others. Substances, such as butter, that are ordinarily seen as yellow had a greenish appearance under the illumination of some of the early fluorescent tubes.

2. To be sure of the color of certain materials, we sometimes try to see them in daylight. We know that materials tend to be a different color under artificial illumination, and we do not know how this color relates to the material's appearance in daylight.

3. To make a colored photograph of a painting on a wall, we do not "shine light" upon the painting directly with an unmasked incandescent bulb but set up diffuse illumination. We reflect "light" onto it from a matte surface, for example. Direct "light" would produce shiny reflections from some portions of the painting and hence nearly colorless areas in the print. Other parts of the painting would not be "lighted" well enough.

4. To bring out interesting effects in viewing or photographing such colored objects as china or porcelain, we use direct illumination so as to cause reflections and highlights. Diffuse illumination would tend to make such objects look dull, flat, and uninteresting.

5. To perceive depth in a scene we must give it some illumination contrast. This means that the illumination we supply must not be diffuse but from a single direction. In this way, not only will some portions of the scene be more highly illuminated than others but shadows will be produced, shadows helpful to an acceptable amount of depth perception.

6. Objects sometimes appear to be different colors in accord with the colors in their surroundings. This is not due primarily to the illuminant. An object appearing blue-green on a white background may appear to be light blue when placed on a black background. On a greenish-yellow (chartreuse) background, it will tend toward a purplish blue. If the background is grayish purple, the object will be brilliant blue.

7. If the illumination of a scene is intense, shadows tend to be dark and objects lying in them are obscured. In such scenes, we look *at* the shadows. If we walk up closer, the shadows appear to lighten and we can look *into* them. With a yet closer approach to a shadow, it lightens still more and objects within it are seen still better. Then it may be said that we look *through* the shadow: The shadow loses its identity as a shadow, and the low illumination that was the shadow becomes more nearly the illumination level for the scene itself.

8. When we go into dimly illuminated places, the color of objects and surfaces largely disappears. In very dimly illuminated places, even though we may still see well enough to get around, all color is absent.

9. The illumination of a scene definitely controls the viewer's mood, which he may attribute to the composition of the scene. For example, outdoor illumination in the afternoon may come from the sun low in the sky, changing the sizes and directions of shadows and other luminous features of the scene and providing for a mood quite different from that at noon.

10. When one looks at a colored object steadily for a moment, and then turns away to look at a homogeneous surface such as the wall of a room, he sees the object imaged against the wall. The color of the imaged

object, called an afterimage, is different from that of the object first looked at and it soon fades and disappears.

Here then is a small sample of the countless variety of situations and circumstances in which we see color. These and many others provide many complex questions for those who study color.

THE STIMULUS

The radiation commonly called light possesses several characteristics that play a role in determining perceptual reaction. Photic radiation is wavelike and usually composed of a wide variety of wavelengths. This combination generally tends to evoke the experience of whiteness. The separation of the components from one another in an orderly array in accord with wavelength produces what we call the *spectrum*.

In the study of color, experimental manipulations may start with spectrally controlled photic sources for targets, in order to determine what is seen, or they may start with experienced situations (confrontation with colors or color patterns) in which the problems are generated by the perceiver. In the latter case, features of photic control needed to produce the phenomena under study are determined secondarily; the color phenomena of possible interest are enormous in number and complexity.

In both approaches, very often stimulus specification, instead of supplying wavelength data and other energistic information, is given in response terms. Instead of describing a portion of the spectrum in terms of its wavelength, it is too often given in color terms like "the green portion of the spectrum" and "the red end of the spectrum." We suggest that if color terms are to be used in stimulus specification, it would be more accurate and helpful to say, "green-producing end of the spectrum" and "red-producing portion of the spectrum." Most often, however, it is preferable to state the wavelength or range of wavelengths that actually apply.

Fundamental stimulus variables

There are three main variables involved in radiation: wavelength, total energy content, and spectral purity. In simple situations, wavelength goes a long way in determining the perceived hue, redness, greenness, blueness (Fig. 5.1). Total flux largely determines brightness, although certain wavelengths evoke a greater brightness effect than others. Spectral purity is the main determinant of whether a given hue is seen to its fullest extent or more nearly resembles a gray or verges into some other hue. When seen to its fullest extent the hue is spoken of as a fully saturated color. Simple desaturation causes a color to appear more nearly gray. Given hues in normal color vision can be produced either by a narrow band of wavelengths (generally spoken of as though only a single wavelength) or by a combination of three particular bands: Normal vision is called *trichromatic*.

1 PURPLISH BLUE
2 BLUE
3 GREENISH BLUE
4 BLUE GREEN
5 BLUISH GREEN
6 GREEN
7 YELLOWISH GREEN
8 YELLOW GREEN
9 GREENISH YELLOW
10 YELLOW
11 YELLOW ORANGE
12 ORANGE
13 REDDISH ORANGE
14 RED

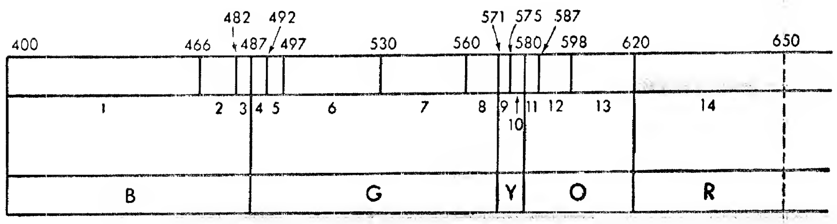


Fig. 5.1. The solar spectrum, in which visible colors are related to the wavelengths that elicit them.

(The various defects in color vision that occur in a small percentage of the general population will be dealt with later.)

Not all portions of the color-producing spectrum of radiation are equally effective. That is, wavelengths do not equally affect the sense cells. The diagram of this relative effectiveness is called a *luminosity curve.* In Fig. 5.2 there are two luminosity curves; the one bounding the black area is the curve for high levels of radiation and the other is for low levels. It will be noticed that maximum effectiveness for the high-level (photopic) curve lies in the region of 550 to 560 millimicrons and that the maximum for the other (the scotopic) curve lies at about 510 millimicrons. A shift from one curve to the other occurs as the illumination of a room is lowered, for example. The shift in the relative lightness or brightness of the various hues in a complex scene is called the Purkinje shift.

Color sources

Some sources of radiation leading to color experiences are: sun, carbon arcs, incandescent lamps, vapor sources such as mercury lamps, and fluorescent tubes. The *array* of wavelengths that any photic radiation source emits is called its spectrum and the spectra of various sources are unlike. Not only the variety of wavelengths involved but also the proportionate amount of energy in the wavelengths in the various sources differ (Fig. 5.3).

Some spectra are *continuous.* They contain a more-or-less complete assortment of wavelengths with no narrow band of wavelengths highly predominant. Other spectra are *discontinuous* and contain prominent narrow bands of wavelength called lines; ranges of wavelengths are absent. Vapor sources are examples of discontinuous spectra.

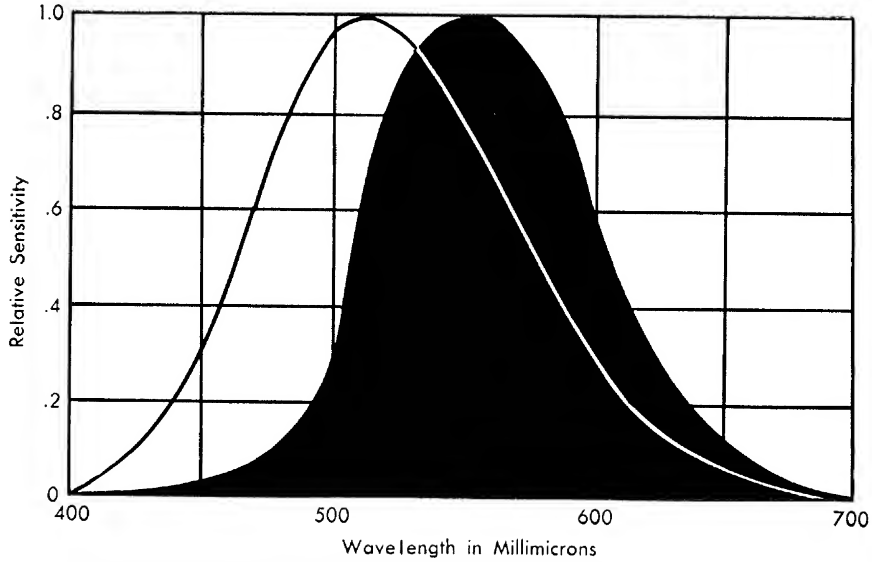


Fig. 5.2. Luminosity curves of the human eye. The contour of the solid area represents the relative sensitivity of the light-adapted eye to various wavelengths. The other curve represents a shift in sensitivity for vision at lower illuminations.

So far we have referred to original sources of radiation. Visual stimuli are of course not confined to such sources but include *reflection* from surfaces and the radiation that has been passed through filters, or substances that selectively absorb and transmit various parts of radiation reaching them. Filters are used to obtain desired portions of the *visible spectrum* by eliminating the portions not wanted. The ideal spectrum is the solar spectrum; it is the portion of the complete *electromagnetic array* that contains not only the color-producing, ultraviolet, and infrared wavelengths but also those that make up the band we call radio waves.

Color filters

The most common filters are used in photography in the form of glass plates. Disk-form filters are slipped on over camera lenses for various purposes. Sky filters are one type; they filter out short wavelength (blue) and help make clouds more prominent in photographs. Common filters are not highly selective. For filtering out all wavelengths except a desired narrow band of a very few millimicrons, special types of filters are used.

A flexible and precise way to obtain narrow bands of radiation is to use a *monochromator*, which with a prism or other device helps select a band of the spectrum by refraction. For the most precise control of the

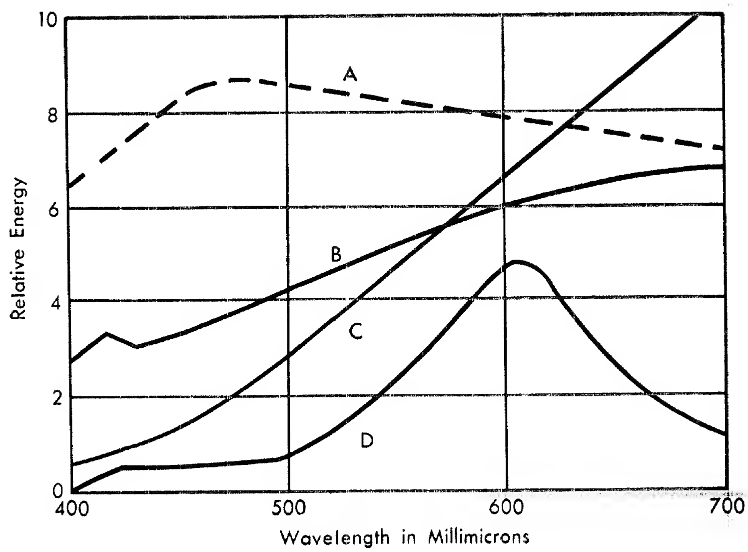


Fig. 5.3. The approximate relative energy of distributions of various sources of radiation within the visible spectrum. A is the sun, B a mercury arc, C a tungsten lamp, and D a fluorescent tube. The curves as drawn have no absolute relation to each other; for example, curve A could have been set at a different level.

very wavelengths and intensities desired, a photic source (a lamp) whose spectrum is known should be used with the monochromator. (The standard illuminant sources are called illuminants A, B, and C.)

Physical processes in photic radiation

Photic radiation from a source to the eye may involve the processes of *transmission, absorption, reflection, refraction, diffusion, diffraction,* or *interference.* These constitute all that happens to radiation once it leaves the source. Some substances *transmit* radiation; it passes through them. Some substances *absorb* photic radiation; radiant energy is transformed within them to other forms, such as heat or mechanical work or chemical processes. Some substances change the direction of the radiation, sending it backward; they *reflect* the radiation. If the radiation reaches the surface of the substance obliquely, the reflection angle has the same value as the incident one. Some substances change the direction of the radiation as it passes through them; this is called *refraction. Diffusion* is reflection by a rough surface or transmission of radiation through a translucent material; in both cases, rays are sent in various directions in a helter-skelter fashion. *Diffraction* is the modification that radiation undergoes in passing along

edges of opaque material or through very narrow slits or in being reflected from ruled surfaces (surfaces with parallel lines scratched on them) and producing parallel light- and dark-colored bands. *Interference* is the mutual effect of two wave fronts meeting. The effect is partial or total cancellation depending on relative energies and whether the wavelengths are the same or different. In some cases, reinforcement instead of cancellation takes place. Interference bands may be set up by different gratings or ruled surfaces. Most of these processes can be manipulated to produce color effects.

COLOR NAMES, SPECIFICATIONS, AND MIXTURES

Number and names of colors

Naming colors depends on a number of factors, some of which lie outside an individual's spectral sensitivity as determined by retinal photochemistry. Some peoples of the world have a very scant vocabulary for color-naming. Rivers (1901) tested several primitive tribes and found that certain tribesmen had only three names: one for items we call red, purple, and orange; one for white, yellow, and green; and one for blue, black, and violet. No finer discriminations were apparently called for in the affairs of the tribe. Need seems to be a great determining factor in color-naming, as exemplified by the fact that Eskimos have numerous verbal responses pertaining to snow whereas non-Eskimos have only a few.

The question of how many colors there are and how names are related to color experiences is important in everyday affairs. Evans (1948) pointed out that there are two kinds of color description, quite difficult to distinguish. One set of terms describes color on an absolute basis; it refers to what he calls the "mental color system." The other set depicts differences between colors and applies directly to the amount and direction of shift in hue, saturation, and lightness. Judd (1932) indicated that there are ten million such distinguishable color differences describable by words. There are far fewer actual color names (the first set). The Maerz and Paul (1951) color dictionary gives less than four thousand, and some of these are only transient names that could be considered synonyms. Thirty-six are single words. A little less than three hundred are compound terms consisting of a color name and an adjective.

The Inter-Society Color Council devised a scheme for naming colors that modifies hue names, such as red, yellow, green, blue, purple, olive, brown, and pink, by the adjectives weak, strong, light, and dark. The word "very" is also included. Furthermore, the words pale (light weak), brilliant (light strong), deep (dark strong), vivid (very strong), and dusky (dark weak) are used. Names for intermediate hues, such as yellowish orange, are

also used. All told, this system totals up to 319 items, given in terms of the Munsell notations (to be discussed later in this chapter). When one tries to use these names for designating transparent materials, some of the terms have to be changed, obviously, because lighter surface colors run to *white* and the colors of solutions run to *colorless.*

Color specification

Two fairly well known systems of color specification involving color samples bear a systematic relation to each other in terms of hue, saturation, and brightness. The first is the Munsell; the second is the Ostwald. In the Munsell (1942) system, the three factors varied in the samples are called hue, chroma, and value, which compare roughly to the three variables just mentioned. They are built into a three-dimensional scheme ordinarily called a color solid and having a vertical black-to-white axis. Radiating from this, the hues are arranged in equiangular spacing (see Fig. 5.4). Chroma is defined as the horizontal distance from the axis. Munsell published a color atlas containing two sets of colored paper samples or "chips" systematically numbered and arranged in accordance with various sections through the solid, one in the vertical and the other in the horizontal plane. The specification of any test color is given in the form of a numerical statement of where it matches the color solid. The Munsell system as improved in 1943 is the nearest approach to a color solid based on the appearance of surface colors. It must be recognized, however, that such a system has limitations. For example, all colors we perceive are not surface colors, and all surfaces do not act alike; hence, all color comparisons we make cannot be made directly by consultation of the atlas.

The Ostwald (1931, 1933) system also employs a color solid in the form of a double cone—that is, two cones base to base (Fig. 5.5). In this solid, the complementary colors (red, green, blue, yellow, and so on) are placed opposite each other around the circumference of the solid. The axis, running from the apex of one cone to the other, is the black-white axis. A vertical section through the Ostwald solid is in the form of two triangles, base to base, or a diamond (Fig. 5.6). The common portion of the two triangles is, of course, the vertical black-white axis already mentioned. The triangles always represent complementary colors. Diagonally in one direction the diamond-shaped blocks represent a series of increasing white and decreasing saturation but constant black. Diagonally in the opposite direction the blocks represent decreasing saturation and increasing black with constant white.

One of the drawbacks to the Ostwald solid is that it is radially symmetrical. In actuality, not all hues involve equal numbers of steps in saturation and would not be represented by equal distances from the vertical black-white axis. This is aptly illustrated by the Nickerson-Newhall experi-

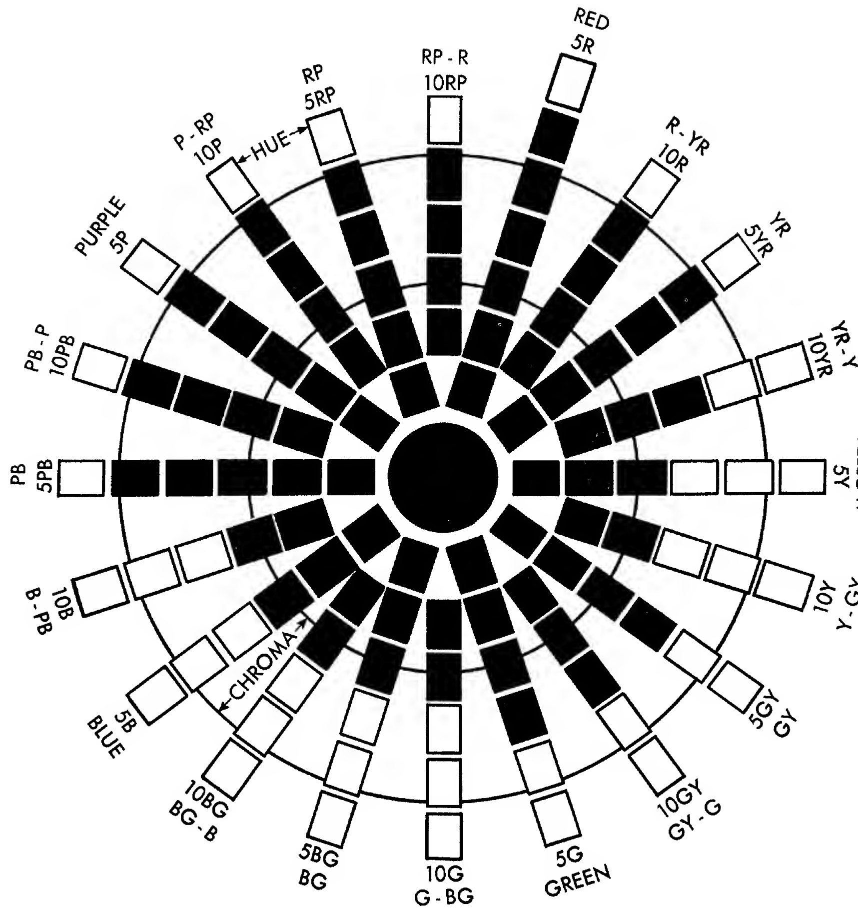


Fig. 5.4. A horizontal cross section through the Munsell scheme (solid) of interrelated colors. Although shown here in black and white, the cross section is meant to represent an array of colored samples (rectangles). The Munsell notation is 5R, 10R, 5YR, etc., for the various hues (radii in the cross section). A second set of labels has been added to make it easier for the reader to identify the actual colors, such as red, yellow-red, yellow-red yellow, yellow, etc. All of the samples in each cross section, when colored, have the same brightness (value). In the cross section shown, the value is 5/. Each cross section is for a different value. Saturation increases along each hue radius, so that the least saturated hues are nearest the central axis of the cross section.

It will be noted that the hues do not provide equal numbers of samples (equal steps of saturation). (Courtesy, Munsell Color Company, Inc., Baltimore, Maryland 21218.)

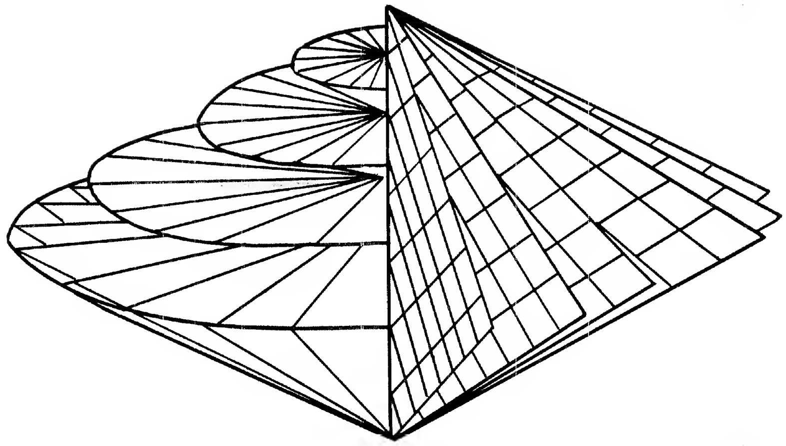


Fig. 5.5. The Ostwald color solid. (R. M. Evans. *An Introduction to color.* New York: Wiley, 1948, Fig. 13.13.)

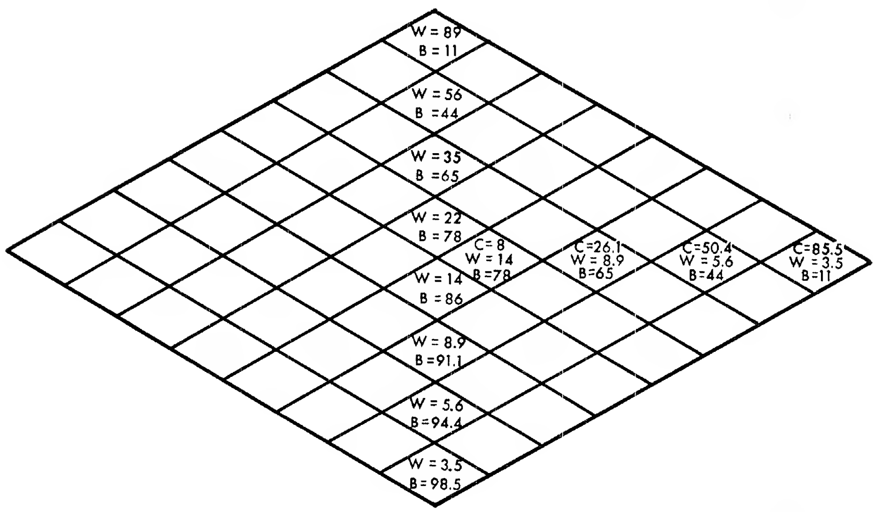


Fig. 5.6. Vertical section through the Ostwald color solid. W = white; B = black; C = "full color"—that is, the hue aside from white and black. Numbers are percentages; only a few are given for example. (R. M. Evans. *An introduction to color.* New York: Wiley, 1948, Fig. 13.14.)

mental color solid based on the Munsell scheme (Fig. 5.7). The main feature of the solid is its demonstration of the inequality of distances from the central axis. It will be noted that nine different levels of this axis are

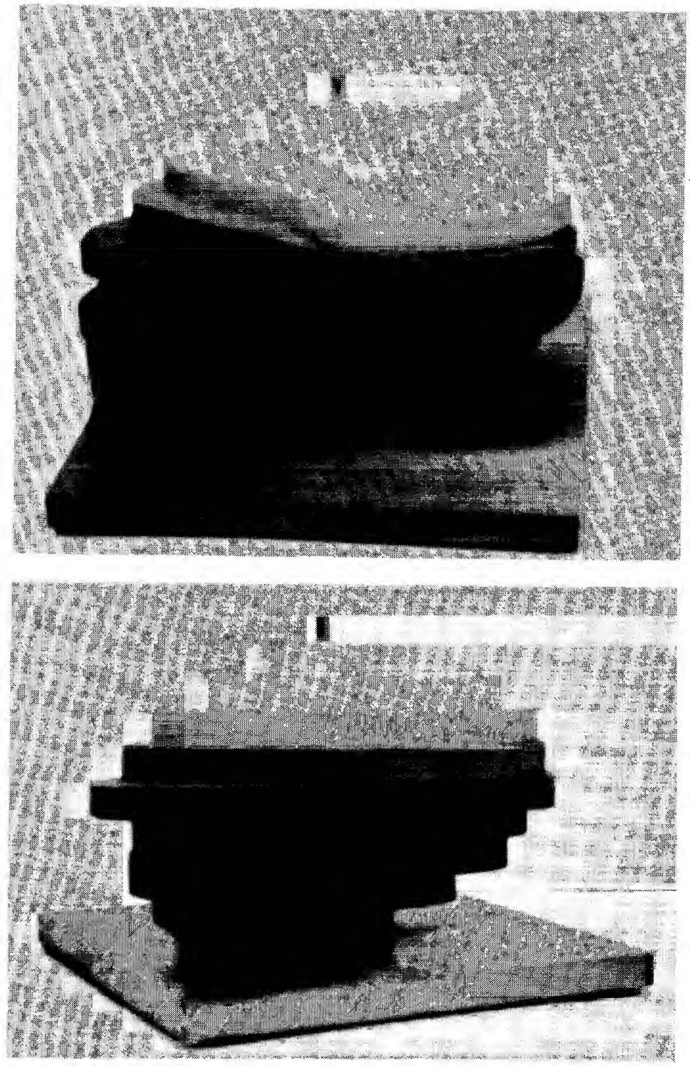


Fig. 5.7. Two views of the Nickerson-Newhall color solid. The solid was originally constructed from color samples of the Munsell system by psychophysical experimentation.

represented in the construction of the solid and that no two of them are alike.

Color mixture: subtractive and additive effects

One problem in dealing with color pertains to what to expect when colors are mixed. We find that in color mixture sensory labels are used in

place of energistic specifications to describe stimuli. The question is more often "what is the effect of mixing red and green?" than "what is the effect of mixing a certain wavelength (or band of wavelengths) with a certain other wavelength or band of wavelengths?" In familiar rather than energistic language, the following may be said. The effect of a beam of red light with a beam of green light is *additive*—more luminance is given and the result is a brighter beam of light. The result of using pigments is *subtractive*—that is, adding some blue pigment to some yellow pigment does not add luminance. Instead, the combination tends to darken. Furthermore, the result will differ in hue: in this case green. The final color will be that represented by the wavelengths that remain after absorption in the two pigments. This group of wavelengths differs from what is not absorbed by either pigment alone and it produces a different color sensation. It is a smaller group of wavelengths and is thus a subtractive effect in luminance.

There has always been considerable interest in *color mixture*, particularly the kind produced by rapidly presenting alternations of different colored surfaces to the eye. This is accomplished by using revolving disks with sectors composed of different colored surfaces. Let us say we use a disk in which the two sectors can be varied: one is seen as green, the other as red. If this disk is rapidly revolved the two sectors are not seen individually and the whole disk takes on a new appearance. With the appropriate spectral reflectances—that is, with the proper red and the proper green—the new appearance is gray. It is necessary to adjust the relative proportions of the two sectors so that the gray will be as nearly neutral as possible; otherwise it will be greenish or reddish.

The revolving disk method helps determine the consequences of mixing various pairs of hues. Any two pairs that do not produce gray when mixed are called noncomplementary colors; those that do are called complementary. Red and green are commonly named complementary colors as are blue and yellow. When three hues (three sectors) are so chosen that each has its complementary lying between itself and the third hue, all other hues can be made by mixing the three together in proper proportions.

The angular sizes of the sectors required to produce a given result are the crude quantitative measures possible in this form of color mixing.

Color mixing can also be achieved by instrumentation. Double monochromators supply two wavelength bands that can be mixed.

COLOR PHENOMENA

Afterimages

We discuss afterimages now rather than earlier because studying their production is a way of studying color vision. Some images produced even

with nonselected portions of the spectrum are colored and can thus be used for discerning certain things about the relative activities of rods and cones.

Something is seen not only when direct photic input (stimulation) is provided but also shortly afterwards. These after-effects, or "after sensations," are usually spoken of as *afterimages.* They are commonly produced by viewing targets of limited angular extents for a few seconds and then either looking at some homogeneous surface (a gray surface, for example) or simply having the fixated target removed without disturbing fixation and without changing whatever the background (context, surround) had been. The observer sees a new area of the same shape as the previously fixated target. The color and size of the new area depends upon several factors. Afterimages are ordinarily not seen in midair but lie on surfaces looked at. The surface on which the afterimage is to be projected can be at a distance from the eye different from that of the original target that is fixated to produce the afterimage. If the new surface is father away, the afterimage will look bigger than the original target and, correspondingly, if the surface is nearer, the afterimage will be smaller. The size of the afterimage is proportional to the distance of the image's projection. This is Emmert's law.

If the target surround and the surface on which the subsequent fixation is directed are neutral gray, the new area (the afterimage) will be complementary to the original target; this new area is called a *complementary afterimage.* It is sometimes erroneously called a *negative afterimage.* But there are *negative afterimages* properly so called: They are produced in the following manner. If an observer views an intensely luminous patch of light and then turns to a homogeneously gray field, he will see a patch either lighter or darker than the field. The lighter patch is called a *positive afterimage* and the dark one is called a *negative afterimage.*

Afterimages last for sizable fractions of seconds or even for several seconds. They appear and disappear and reappear. The total train of alternations may occupy a number of seconds, during which time they decline in impressiveness.

The microtemporal after-consequences of photic stimulation may be studied by very briefly exposing a stimulus of relatively high intensity (a fraction of a second) followed by no illumination of either target or surround (a completely "dark" room). Under such conditions, a sequence of seven afterimages is often observable. Berry and Imus (1935) listed them as follows: (1) A positive image appearing about 1/20 of a second after target exposure and lasting for about another 1/20 of a second. (2) A "negative" or dark period follows. (3) The second positive afterimage, called Bidwell's ghost or the Purkinje image, appears at about 1/5 second and lasts for that much time. (4) A second dark period follows. (5) The third positive image, which is called the Hess image, appears. (6) A third dark period follows. (7) A fourth, very weak positive phase appears.

McDougall (1904) used a technique that spread the afterimages and the interspersed dark phases out in a spatial array. He used a revolving slit of 2° in angular subtense, which moved in front of a glass surface illuminated briefly from behind. The observer saw a series of light and dark bands in spatial sequence. Some of the bands have been identified, one for example as Bidwell's ghost.

Color adaptation and conversion

As one deals with color in practical and experimental situations, he is impressed by two apparently diverse principles. Color is seen to be a facile and changeable thing, depending largely upon the relationship of one part of the scene to another. Two colors seen as juxtaposed are always different from what they would be were the target simplified so that only one color were seen. It can be said, then, that color of a limited target is not fixed in its relationship to the impingement that produces it. On the other hand, colored surfaces do not seem to change much under a wide variety of illuminations. They tend to look somewhat the same in most cases regardless of whether the illumination is artificial or natural (the sun). Although these effects seem diverse and unrelated, they are both due, in part, to the mechanism of color adaptation.

A target seen after the eye's adaptation to a target of a different spectral composition appears to be different from how it would appear without this preexposure. On the other hand, various targets that ordinarily differ in their color may look alike when they are viewed by eyes that have been previously adapted to different wavelengths.

When one's gaze is fixated on a colored area, adaptation of the eye to the area and its immediate surrounds sets in. Though the appearance of the fixated area does not immediately change, the area next viewed, when the eye shifts position, will be affected. This effect depends on the length of the previous fixation, the intensity of stimulation, and the area of the surface viewed. Increasing these factors works toward an increase in the persistence of the effect. Full adaptation occurs quite readily if the viewed target is of moderate intensity and if the eye comes upon it from darkness. As fixation upon such a target is prolonged, the consequent adaptive effect is more persistent, as demonstrated by the longer time required for adaptation to a new target of low intensity.

In a complex target, various portions reflect (or emit) different wavelengths at different luminosity levels. Adaptation to different portions of the target is different: Some portions adapt to one part of the spectrum and others to other parts. A shift of the eye or a sudden exchange of targets causes consequences that can be attributed to this differential adaptation.

Let us say that the new target is of the same spatial pattern as the original one, the two differing only in the wavelengths involved in some of

their various areas. Areas of the new target that happen to involve same wavelengths as in the old will evoke reduced response because of previous adaptation. Areas involving new wavelengths will not have been preadapted to these wavelengths; because no preadaptation had occurred, they will evoke strong responses. A whole new set of relationships between the effectiveness of the various areas is produced.

In this shift, the spectral composition of the illuminant—as well as the spectral reflectances of the target surfaces—plays a role. In any complex target, the outcome is also extremely complex, and only in more recent years has a reasonable understanding of the matter been achieved. This is expressed in Helson's (1964) account which involves his adaptation level theory. Helson speaks of certain complex phenomena usually discussed in adaptation as "color conversion." The following is Helson's slightly modified statement of Helson and Michels' (1948) earlier statement.

> The principle, based on work with reflecting samples on nonselective surfaces states: In every viewing situation there is established an adaptation level or neutral region such that stimuli with reflectances above this level are tinged with the hue of the source of illumination, stimuli with lower reflectances take the afterimage complementary to the hue of the illuminant, and stimuli with reflectances near AL [adaptation level] are either achromatic or weakly saturated and of uncertain hue. In order that a highly reflecting surface appear achromatic it is necessary that its spectral reflectance be such that, when multiplied by the spectral energy distribution of the illuminant, it yields the specifications of the corresponding achromatic point. But highly reflecting surfaces necessarily depart from this condition toward the hue of the illuminant. According to Equation 15 a stimulus of very low reflectance would be achromatic only if its spectral reflectance, multiplied by the spectral energy distribution of the illuminant, were to yield the chromaticity coordinates of the surround. The reflectance of selective surfaces can depart from this requirement in one of two ways: (1) favoring the dominant wavelength of the illuminant and yielding high reflectance, and (2) favoring other wavelengths, thus causing the color to shift toward the complement of the illuminant. However, this effect alone cannot explain the behavior of nonselective surfaces of low reflectance. The color of such surfaces must be due to the afterimage complementary effect noted with spots of low brightness. The results obtained in the study therefore agree with the principle of color conversion obtained from observations on reflecting surfaces. (Helson, 1964, pp. 169–170.)

An illustration of the operation of color conversion is found in the Land colors (Land, 1959). The Land procedure photographs a scene on black-white film through a long-wave (or "red") filter. Wavelengths in the scene, in the range of from 585 to 700 millimicrons, affect the film more than shorter wavelengths. The scene is also photographed through a medium wavelength filter (passing radiation of from 490 to 600 millimicrons).

This filter emphasizes this band of wavelengths. When positives of these two films are projected on a screen in exact register (occupying exactly the same space on the screen), a reproduction of the original scene in color results when the long-wave positive is projected with illumination coming through the original "red" filter and the medium-wave positive is projected with illumination from a common incandescent lamp with no filter. However, if the red filter for the long-wave positive is replaced by a "green" filter, the colors in the resulting scene are reversed. This is as would be expected from the principle of color conversion.

Helson's explanation is as follows: When positives are made from the two films using the two filters as described above, the long-wave positive reproduces the red-yellow colors of the photographed scene, whereas the middle-wave positive reproduces the green-blue colors in near-white. Supposing the existence of an intermediate adaptation level, the portions of the screen above this level will be viewed as red to yellow, the portions near the level will be colorless, and the portions below the level will show up as various mixtures of the "afterimage complement" or green-blue.

Land supposed that the colors he produced from just two complementaries could not be accounted for by classical explanations of color vision, since normal color vision is supposedly based on three complementaries. Helson's explanation, premised on the idea that adaptation is involved (where Land had rejected it), covers the situation very well. A difference here between Helson's concept of adaptation and many psychologists' conception is that his does not involve the factor of appreciable duration whereas classical adaptation does.

Color contrast and induction

In dealing with color effects one is faced not only with relating photic input to body process and to sensory end result (the color produced) but also with the fact of spatial adjacency of various diverse inputs on the retina. Two adjacent areas of the retina provided with different spectral inputs produce effects that are not accounted for by the rules governing the simple relation between wavelength and color end result. The effects are due to adjacency of the two inputs. We are, in more familiar terms, speaking now of color induction and color contrast. A target seen as red looks still redder when adjacent to another target area seen as green. This contrast effect is produced with achromatic targets as well. The processes produce simultaneous contrast, but contrast may occur when the target fixated looks green and is exchanged for one that looks red. The red is redder than otherwise by reason of the exposure to the previous target. Thus, since contrast may be of two forms, color induction is of two forms. Successive induction is dependent upon adaptation (at least in part), and hence it is relevant to the present discussion of adaptation.

Relation of hue and saturation to intensity

The relation of perceived hue to intensity of radiation has been studied by several investigators, including Purdy. Purdy (1931) used a target with two portions, the intensity relations between which bore a ratio of 10 to 1. A large field was matched with a small field that was less intense. In the typical set of results shown in Fig. 5.8, the curve shows the amount of dis-

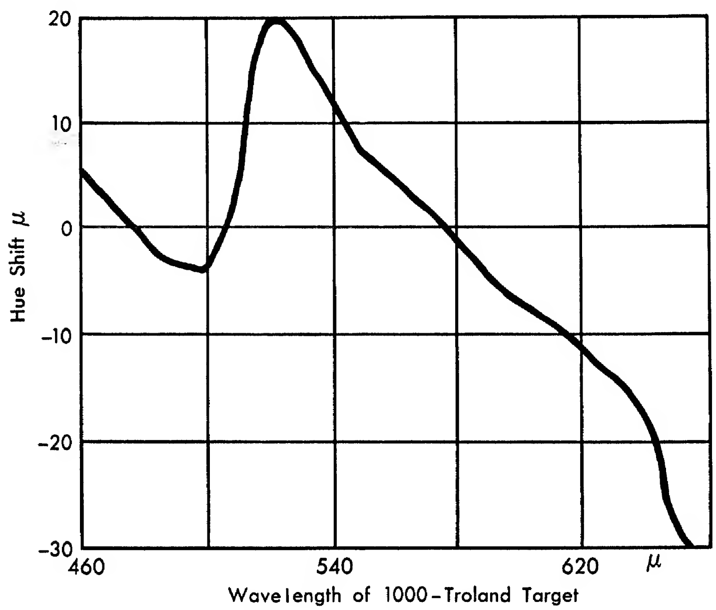


Fig. 5.8. Change in hue produced by a change in intensity from 1000 to 100 trolands. Targets of these two intensities were matched and a wavelength shift was found necessary to match the hues. (D. M. Purdy. Spectral hue as a function of intensity. *Amer. J. Psychol.*, 1931, 43, 541–559, Fig. 1.)

crepancy in wavelength between the two fields that had to be used to make the two hues match. In the extreme left portion of the graph, it will be seen that the small matching field had to have a slightly longer wavelength than the test field. As the wavelength for the test field was lengthened, the wavelength for the matching field had to be shortened so as to retain the hue match between the two. At a little above 500 millimicrons, the matching field had suddenly to be shifted toward the longer wavelengths. This effect reached a peak in the region of about 525 millimicrons. From there on, the wavelength of the matching field had to be gradually reduced to maintain the hue match. In the region of about 575 millimicrons, the two fields matched when their wavelengths were similar. As longer and longer wavelengths were compared, the wavelengths of the matching field had to

be reduced more and more until, as is seen by the graph, the discrepancy became very great.

The results are shown in a different way by Fig. 5.9, in which each line represents a constant hue. It will be seen that not all the lines are straight and perpendicular. Many of them shift to the right or left, indicating that the wavelengths represented change as the value of the ordinate of the graph changes (as the luminance changes). At three places along the abscissa (wavelength) there are invariant (stable) points. These same three points are shown in graph 5.8, indicated by arrows where the curve is at zero hue shift.

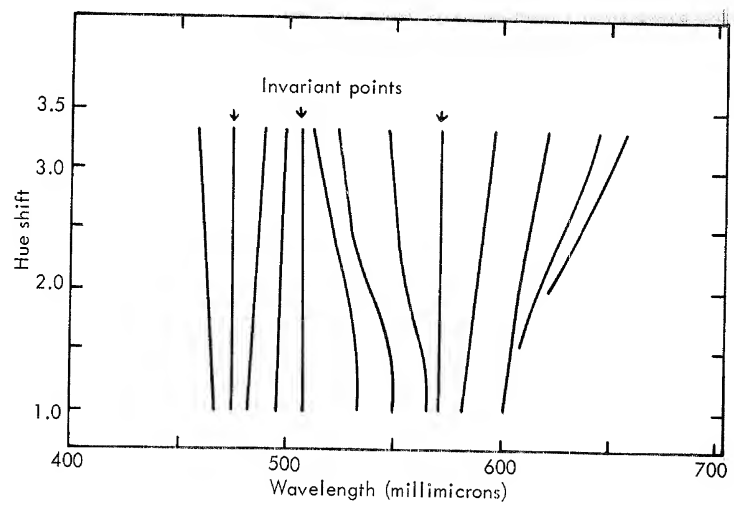


Fig. 5.9. A set of curves obtained by Purdy to indicate the relation of constant hue to wavelength and luminance. They represent another way of indicating the results in Fig. 5.7. (L. M. Hurvich & D. Jameson. Some quantitative aspects of an opponent-colors theory. II. Brightness, saturation, and hue in normal and dichromatic vision. *J.O.S.A.*, 1955, **45**, 602–616, Fig. 9.)

Abney (1913) earlier studied the relation of intensity to hue. He studied a much wider range and came to the conclusion that all hues tend to move toward blue or yellow at high intensities, toward red or green at low intensities. This conclusion is not contradictory to that derived from Purdy's experiment.

Modes of color appearance

Colors may be seen in several ways—that is, color may be an aspect of various kinds of perceived situations, which may be divided into five classes.

They are generally spoken of as *modes* of perceiving colors, and they are: (1) the aperture, (2) the illuminant, (3) the illumination, (4) the film, and (5) the object modes of surface and volume.

The aperture mode is that in which color is seen without regard to its distance and its being a property of a surface or any object. One of the best illustrations of the appearance of aperture colors is the color that is seen through some optical instrument, such as a microscope or a spectroscope, in which the field is uniform and not seen to be that of the surface of any object. The same result may be obtained when viewing a spectral target through a cardboard mailing tube.

The illuminant mode is assumed when one views a source of photic radiation, such as an incandescent filament, an arc lamp, or the surface of an opal-glass window of a lamphouse when illuminated from the side opposite the viewer in a darkroom.

The illumination mode is assumed when one detects that the color of a surface is "due to" its illumination or that the illumination of the room is affecting the color of objects in it.

The film mode of seeing color is produced, generally, by photic radiation falling on the rapidly moving blades of a fan or an episcotister (a rotating disk with either open or different colored sectors). The film is translucent. One sees not only it but also objects beyond it.

The two object modes, surface and volume, have to do with the perception of the properties of objects. Color seems to be an intrinsic property of the object itself rather than of the light that falls on it. Seeing color as a property of a surface is so convincing that at times it takes some peculiar demonstration or explanation to help a person realize that color is a function of illumination as well as of surface properties.

In other cases—for example, in the volume mode of seeing color—we do not necessarily see the surfaces of objects as standing out in distinction and we are able to look through the objects, as vessels of colored liquids. The color we see is distributed through the liquid and is a three-dimensional affair.

Depending upon the mode of viewing it, various properties of color emerge.

Properties of color

When color, particularly a colored surface, is spoken of, a number of properties in addition to hue, brightness, and saturation are included. Some seem to pertain to color the way hue, brightness, and saturation do. Others are effects that do not pertain so much to the color itself as to collateral effects attributed to color. In the list that follows, a number of properties of the first sort are included.

hue	pleasantness or unpleasantness
brightness or lightness	pronouncedness
saturation	area
warmth	location
hardness	

Transparency is another feature attributed to color as a property. It may be that, but it would seem that transparency has more to do with the material that carries the color (color in varnishes as in contrast to color in paints).

Another dubious property of color is *shape*. It is often listed as a color property, as when we say that colors depend upon the shape of the object to which they pertain. Here one needs to remember an infrequently observed principle: in using the term color one refers to a perception. Shape is a characteristic seen at the same time that color is seen. They can be said to be two parts of a simple overall perception. It is not proper to use one part of a given response (or perception) to account for another part of it. If one were free to say that the shape of an object changes its color, one might find that he could say that the color has an effect on perceived shape. Neither statement is quite legitimate. For causal explanations, one must go to body processes.

Still other qualities attributed to color are *gloss, luster, sparkle, texture, volume*. Here again are terms that do not fall into a single category. Gloss refers to an effect produced by the ratio of specular to diffuse reflection of target surface. Specular reflection is reflection that is more pronounced in some direction than others; it is the opposite of diffuse reflection. It is therefore not a property of color at all, nor of wavelength in particular. It is a property that pertains to surfaces seen as gray or white or black, as well as to surfaces with a definite hue. Luster is a perceived surface and intensity property; it has not been well-defined and its origins are not clearly understood. Texture is not specific to wavelength or to hue but to structural composition of a surface or to the minute variations in texture or in lightness. Other color phenomena will be dealt with in Chapter Six on perceptual constancies.

THEORIES OF COLOR VISION

For long over a century, men interested in vision have produced theories of color vision based on either suppositions or knowledge about the photochemistry of retinal cone pigments and on psychophysical data stemming from relating colors seen to portions of the spectrum used as stimuli. More recently, information regarding neural processes in the visual system ("the optic pathway") has been utilized in theory-building. Our attention

will be given first to the classical theories of Young and Helmholtz and of Hering. While there have been numerous theories differing from each other in limited particulars, these two provide a basis for understanding what color theories in general contain and how provisional explanations have been achieved.

Young first presented his color vision theory in 1807, and Helmholtz began his contribution in 1852. The names of the two men are customarily bracketed together as authors of a trichromatic theory. A trichromatic theory states that all the perceivable colors can be obtained from combining three appropriate wavelengths or three bands of wavelengths. It is supposed that there are three fundamental photochemical processes each of which is elicited to some degree by different parts of the spectrum.

Differing from this trichromatic, or three-component, theory, Hering in 1878 and in 1920 believed that there are four primary colors, blue (about 470 millimicrons), green (about 500 millimicrons), yellow (about 570 millimicrons), and red (mixture of red and violet). His sort of theory is known also as an opponent-color theory. Red and green are one pair of opponents; blue and yellow are another pair. In this theory, colors intermediate between the primaries oppose each other also. The primary colors possess important properties not possessed by their intermediates. The primaries do not shift in hue as brightness changes, and they keep their opposition in producing an achromatic effect (gray) and in simultaneous contrast. The properties of opponent pairs are thought to depend upon paired antagonistic photochemical processes, for example, a red-green process, a yellow-blue process, and a white-black process. There are supposedly subprocesses whereby the red opposes green, blue opposes yellow, and so on.

Hering initially characterized the opposing subprocesses as assimilative and dissimilative. Processes for white, red, and yellow were dissimilative—that is, they were breakdown or catabolic processes. Processes for black, green, and blue were build-up or assimilative processes. Intermediate hues were thought to be dependent upon the interaction of assimilative-dissimilative components, as for example the reaction of the processes for blue and red to produce violet.

The present-day version of the opponent-color theory is described by Hurvich and Jameson (1955), who developed the first quantitative statement of such a theory.

STUDIES ON BODY MECHANISMS

Granit's work relating to color theory

The physiological studies of Granit (1947) that began in the 1940s produced information of considerable theoretical significance, although

they have not provided data interpretable exclusively by either of the two types of theory just described.

Granit recorded electrical responses, evoked by inputs of different wavelengths, in single or clustered optic nerve fibers and in ganglion cells in the retinas of several species. Microelectrode technique made this possible. In recording from primarily rod-containing eyes, spectral sensitivity curves were found to be broad. They tallied with minor deviations to the absorption curve of visual purple, a rod pigment. Granit called them *scotopic dominator curves.*

In the light-adapted eye of the cat, modulator curves were not obtainable. Instead, he found narrow-bound curves of sensitivity with maxima at approximately 450, 540, and 610 millimicrons; he called these *modulator curves.* Various animal species differed from each other in the sorts of dominator curves and modulator curves exhibited. The findings tallied with cone-rod eye composition.

Granit described how modulator activities may combine to provide for the human luminosity curve and how hue discrimination and luminosity are brought about.

DeValois' work in the lateral geniculate body

More recently, DeValois (1960) studied the electrical responses of the lateral geniculate body of the monkey to spectral stimuli. He found cells in the dorsal layers that produced "on" responses and cells in the ventral layers that produced "off" responses. Certain cells in the intermediate layers produced "on-off" responses; these cells responded only to inputs from one eye or the other but not to both. Varying the photic intensity over wide ranges did not shift the responses of "on" cells to "off" responses. Increasing input intensity raised the average number of impulse spikes in the record. Many of the "on" cells were sensitive to only a narrow band of the spectrum. Some cells toward the edges of the lateral geniculate body showed sensitivity to two bands of wavelengths. As the eye was shifted from a dark to light adapted state, the sensitivity peaks shifted, whereas other "on" cells showed no such shift.

Cells that exhibited both "on" and "off" responses exhibited "on" responses to one band of wavelength and "off" to another. For example, a cell may respond during photic input and be quiescent when the input is terminated. If an input of a different part of the spectrum is used, the cell does not respond during input but will respond at the termination of the input. Such a cell is insensitive to inputs of intermediate wavelengths. There seem also to be cells that respond to two wavelengths but differently. They produce for example, an "on" response to the short ("blue") end of the spectrum and an "off" response to the yellow-producing portion of the spectrum.

Measurements on the characteristics of receptors

Recently Marks, Dobelle, and MacNichol (1964) recorded difference spectra for single cones in the eyes of human subjects and monkeys. Brown and Wald (1964) did this for the human eye only. Marks and his colleagues found three classes of cones in the eyes of both humans and monkeys. The absorption maxima for photic radiation were at about 445, 535, and 570 millimicrons. The findings of Brown and Wald were quite similar: at 450, 525, and 555 millimicrons, they also made observations on single human rods, showing a maximum of 505 millimicrons.

Marks, Dobelle, and MacNichol summarized their findings in the following way: (1) The primate parafovea contains three kinds of cones, each seeming to have a single predominant pigment. (2) The pigments absorb energy maximally from three distinct regions of the spectrum. (3) The blue receptor is a cone, not a rod. Its absorption maximum is for a shorter wavelength than for rhodopsin found in rods. (4) Cone pigments seem to have the same order of concentration and sensitivity as those found in rods.

DEFECTIVE COLOR VISION

Forms of color defect

Defective color vision, sometimes called *color blindness* or *anomalous color vision,* is an inherited condition. In it, confusion in discriminating and naming of the various target portions that give rise to the normal array of color is manifested. Defects in color perception occur in reference to hue, saturation, and brightness or lightness.

There are three principal forms of color defect. The first is total color blindness, or *monochromatism,* in which all hues and saturations of them are absent but variations in brightness can be detected. The next condition is partial color blindness or color weakness in which only two distinct hues are perceived regardless of the spectral content of the radiation reaching the eye; this is called *dichromatism.* The third kind of defect is known as *anomalous trichromatism;* it differs least from normal color vision (which is known as *trichromatism,* since radiation from any properly selected three portions of the spectrum can be combined to match a chosen color). In dichromatism, two portions of the spectrum provide the matches. In anomalous trichromatism, three portions of the spectrum are required to match all colors but the matches vary more from test to test.

There are nine subvarieties of the three principal kinds of color defect, so complex as to warrant omission of their description. They are named as follows: (1) typical total color blindness, (2) atypical total color blindness,

(3) green blindness (deuteranopia), (4) red blindness (protanopia), (5) absence of blue and yellow perception, (6) a weakness for the perception of colors in the short-wave end of the spectrum, (7) green weakness, (8) red weakness, and (9) blue weakness. Some of these forms are exceedingly rare. The most prevalent forms are atypical total color blindness, about 2 percent males and about 1/70 as many females; green blindness, 1 percent of males and 1/10 percent of females; red blindness, about 1 percent of males; green weakness, 5 percent of the population; and red weakness, 1 percent of the population.

A great deal of the work on color vision consists in finding out more about the nature of various color defects. Such findings help in the construction of color theories (statements about the understanding of body mechanisms underlying color vision) and in checking on and modifying theories already in existence.

Deuteranopia

One form of dichromatism is deuteranopia, in which relative spectral luminosity does not differ much from normal vision but in which all colors can be achieved only by mixtures of two primaries, one from one end of the spectrum and one from the other end. Somewhere between these two extremes is a neutral point where hue is best discriminated. Shorter wavelengths give rise to blue, longer wavelengths to yellow. The saturation of the colors increases toward both ends of the spectrum. Yellow, orange, red, and green cannot be discriminated from each other when saturation and brightness are made the same. Blue, violet, and bluish purple are different for the deuteranope only in brightness and saturation but not in actual hue.

Graham and Hsia (1958) determined the absolute luminosity for a subject with normal vision in one eye and mainly deuteranopic vision in the other. Both eyes seemed to be equally sensitive to the part of the spectrum for red, but the color-blind eye was definitely less sensitive for blue and green. By a matching technique, the experimenters found that the subject saw only two hues with the defective eye. They matched all wavelengths greater than about 502 millimicrons by presenting a wavelength of 570 millimicrons (yellow) to the normal eye. The shorter wavelengths were matched by a wavelength of 470 millimicrons (blue) presented to the normal eye.

Berger, Graham, and Hsia (1958) found that the luminosity deficits exhibited by this subject held at intensities well above threshold.

Tests for color vision

Tests for color defects have been standardized, but they tend to have certain limitations, some owing to their length, some to their failure to deal

with all the principal kinds of defects, some to the marked difference between them and the conditions of everyday life in which color defect is significant. A description of all best-known color tests would be too lengthy and complicated for us here.

One form of screening test for color-vision defect is the so-called pseudoisochromatic plate test. The plates are cards covered with various colored dots arranged in random relations except for certain dots that form given figures within the dot field. Subjects with normal color vision see the figures. Subjects with certain defects see the figures on some of the plates but not on others. The earliest of this form of test was the Stilling test produced in Germany in 1875. A Japanese form, the Ishihara test, was produced in 1917. It was meant to detect protanopic and protanomalous defects as well as the deuteranopic and deuteranomalous. A Russian form, the Rabkin test, appeared in 1939, and in 1944 the Dvorine, an American test, came out. In 1955, the H-R-R plates of Hardy, Rand, and Rittler appeared in this country.

In 1943, Farnsworth produced a 100-Hue test that used Munsell color chips to be arranged in order of hue. This is somewhat similar to the old Holmgren yarn test, which involved sorting yarn samples into groups according to hue.

The more precise nature of a subject's color discrimination is determined by instrumentation. The anomaloscope is one form; the most widely used instrumentation is that invented by Nagel in 1898. Hecht and Shlaer also produced one more recently.

A double monochromator may be used, an instrument by which a narrow band of the spectrum can be selected for color observation. One target field can be held constant and the other varied step by step by moving along the spectrum by small amounts. Normal vision detects color differences as small steps are made; with color defectives the steps may be enormous without the emergence of a hue difference.

TEMPORAL FACTORS IN PRODUCING COLOR

None of the better-known theories of color vision recognize the fact that temporal features of photic input participate in determining the color seen. For these theories temporal factors seem not to exist and the only differential of consequence in the input is wavelength. This is in spite of the fact that for more than a century color has been shown to be producible by whole-spectrum inputs, the inputs that generally produce white or gray.

Fechner (1838) reported color effects from whole-spectrum targets. Benham (1894) devised a top (a spinning disk) half white and half black with some concentric black lines drawn on the white sector. When the disk revolved at about 5 cycles per second under moderate illumination, various weak colored rings appeared.

Much more recently, certain workers have become interested in the role of timing of intermittency of stimulus input in the modification of color effects (Bartley and Nelson, 1960; Nelson and Bartley, 1961; Ball, 1964; Ball and Bartley, 1965; Bartley and Ball, 1966; Ball and Bartley, 1966). These authors used stimuli of selected wavelengths. The colors produced were radically changed in hue, saturation, and brightness when intermittent stimuli were substituted for steady stimuli. These experiments were special examples of the technique that first produced the phenomenon Bartley called "brightness enhancement." The only essential difference between his original studies and these was that his original work employed whole-spectrum ("white") stimuli and his later work employed selected portions of the spectrum (varying from broad bands provided by the common Wratten filters to very narrow bands provided by either a monochromator or special filters).

All these authors insist that any adequate account or theory of the mechanism that produces color must be built upon not only the traditional information about receptor photochemistry but also the understanding gained from temporal manipulations of stimuli. This is not to be thought strange, for most of the many processes involved in producing color are actually neural rather than photochemical. Since timing is one of the chief factors in the operation of neural systems, timing of the features of stimulus input should be expected to play a causative role in color outcomes.

For example, Ball and Bartley (1965) found that if there are shifts in hue for stimuli at 480 millimicrons, they are toward colors produced by steady stimuli of shorter wavelength (purplish blue, for example). With inputs at 500 millimicrons, the results are variable, depending upon PCF (pulse-to-cycle fraction). With stimuli ranging from 510 to 560 millimicrons, the shift is always upward, toward the colors obtained with steady stimulation at longer wavelengths. At 580 millimicrons no hue shift is producible, and with stimuli at 600 to 680 millimicrons the hue shifts are always downward, toward colors produced by shorter wavelengths. PCFs above 0.25 produce few hue shifts for intermittent stimuli of any wavelength. Thus it is seen that there are two neutral or pivotal points for hue shifts, one at 580 millimicrons and one at 500.

Nelson, Bartley, and Mackavey (1961) applied to the use of pseudoisochromatic plates the findings already obtained in the study of the effects of intermittency on hue shifts. They supposed that using certain rates of intermittency might change color perception in ways that would disenable normal observers from seeing the figures on certain plates. Their experiments substantiated this. More recently, Ball and Bartley (1966) have repeated the study with more precision and have used color-deficient as well as normal observers. At certain rates and with certain PCFs, both normals and color deficients saw figures on the plates less effectively. At certain rates of intermittency, the observers with color defect were able to do better than

with steady illumination of the plates. The latter fact supports the idea that determination of color vision is partly at loci further along in the optic pathway than at the receptors, where selective absorption of various photic wavelengths is the definitive factor.

SUMMARY

The chapter was divided into eight parts: introduction; the stimulus; color names, specifications, and mixtures; color phenomena; theories of color vision; studies on body mechanisms; defective color vision; and temporal factors in producing color.

In the part dealing with stimulus, the fundamental impingement variables, color sources, color filters, and physical processes in photic radiation were discussed.

The next part began with the number and names of colors, followed by a discussion of color specification that included both the Munsell and the Ostwald color systems.

The part on color phenomena included afterimages, color adaptation and conversion, contrast and induction, and the relation of hue and saturation to intensity. The modes of color appearance and the properties of color were also described.

The next part of the chapter discussed color theories briefly.

The following part described certain studies on the neurophysiology of color perception.

Then came a section on color defects. The chapter was concluded by the presentation of material showing that the temporal patterning of photic input is a factor in determining the perception of color.

3

SIX

Perceptual Constancies

One problem in perception is to account for how things look. In so accounting, we use stimulus-response psychology, which relates the organism to the world as the physicist describes it and is the stock-in-trade of the natural scientist. Right away we encounter the task of explaining the existence and stability (or relative permanence) of the objects we see. There is no simple relation between sensory input and sensory end result: Although an input varies in many ways and over wide extremes, things seen remain, keep their identity, and seem stable in their qualities. This is called constancy. The phenomena subsumed under the label of constancy are quite varied and complex, and it is questionable whether the term is the best one to cover them all. That is, several ways of approaching the matter lead to different labels.

Using a given sensory end result (an experience) as the reference, the problem can be stated as the question: What are the stimulus inputs (or impingement conditions) that will produce the end result? It is very often found that an array of very diverse inputs will be equivalent, or nearly so, to each other. Therefore, we deal with *equivalence* and our problem is to define what produces it.

On the other hand, we may look at the matter from a different standpoint: How stable will the end result be if we change the impingement conditions? How much alike will a given sheet of "white typewriter paper" appear in very low illumination and in bright sunlight? We unwittingly seem to ask two questions in this second way of looking at the matter. One is whether we can be sure from visual appearance that the sheet seen in sunlight is the same sheet as the one seen in the dim illumination. This is a question of identification rather than full sensory similarity. The second

question is whether, once the identity is taken to be the same, the *lightness* of the paper is seen to be the same in the two cases.

The trick is that in no case is the lightness or other property of the object fully undetermined by its context. The more we try to extract context or reduce its effect, the more likely it is that the object will vary in its appearance in simple relation to such input variables as intensity, duration of presentation, spectral composition, angular subtense, and features intrinsic to the item involved.

The foregoing generalizations make it evident that we speak not only of *constancy* but of *identification* and *equivalence* as well. Helson prefers to use the term "compensation," at least in dealing with colors. It implies that the visual mechanism compensates to certain limits for shifts in viewing conditions; then approximations to constancy begin to vanish. The mechanism is one of *color conversion*. The principle of color conversion is more comprehensive, is relevant to a range of conditions wider than that in which conditions of constancy are thought to hold. This chapter will deal with the phenomena in vision commonly called examples of constancy: lightness, size and distance, shape, and color.

LIGHTNESS OR WHITENESS CONSTANCY

In the discussion of brightness discrimination in Chapter Four, much was said that demonstrated lightness constancy. To that discussion, we'll add some examples here. Lightness constancy is to be regarded in terms of the relative weights given two important factors in visual stimulation: (1) the intensity of target illumination by some source of photic radiation and (2) the amount of reflectance of the target itself. We know that the reflectance of a target does not vary as intensity of radiation is varied. That is, a target always reflects a *constant percentage* of the radiation falling on it when intensity is the only variable manipulated. If the property of lightness were dependent on this factor, then the target would look equally light no matter how weak or intense the radiation reaching it. Were lightness to depend upon quantity of light falling on the target, lightness would vary in keeping with radiation intensity. Lightness does not strictly follow either of these rules. If it followed the first rule strictly, perception would manifest complete "constancy." To the extent that it does not follow the rule, complete constancy is departed from. Some experiments in constancy provide a measure of just how closely complete constancy is approached.

Illumination

Although we shall see that the apprehension of illumination as such is not a necessary factor in producing the kinds of results we are to deal with, it must be recognized that illumination may be involved in various ways in

various situations. It must also be recognized that visual results depend in a large measure upon the way illumination is involved in a given situation.

There are several ways that illumination may reach the eye. The use of apertures is one. One way to provide an aperture gray is to set up a *hole* arrangement. A screen is provided with a hole that subtends a few degrees of visual angle at the eye. An illumination source is concealed behind the screen. A still better way is to use two rooms, with the hole in the wall between. The illumination falls on some reflecting surface that can send radiation to the observer, as in Fig. 6.1. The hole can be seen as an

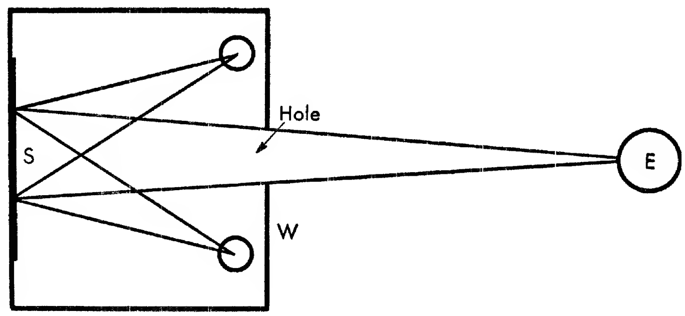


Fig. 6.1. Illumination arrangement to produce an aperture gray. Radiation falls on a surface (the opposite wall of an adjoining room) and is reflected through a hole to the room of the observer, whose eye is E. The hole seen as a gray area is now the target on a well-illuminated background, W.

aperture filled in with a certain gray. The light does not seem to come from a definite surface at the plane of the screen, or even at some distance behind the screen, unless the area viewed through the hole is textured, that is, inhomogeneous. If, however, the observer is predisposed toward seeing surfaces, the hole *may* be seen as a surface.

Illumination in some situations may be tapered due to progressive distance from the source. This is called illumination perspective and is often perceived as a space dimension. Artists use tapered lightness to give the visual effect of progressive distance away from the viewer.

Illumination may encounter obstructions, in which case shadows are cast. Shadows are areas of diminution of illumination within which object lightness constancy tends to be high. Here again, we encounter the need for distinguishing between the observer's ability to *identify* lightness of objects within the area and actually to see the area as having a lightness different from others in the visual field.

Equations (matchings) of lightness between the area seen as in shadow and an area seen as outside the shadow are difficult to make. Let a screen be set up in front of the field just implied, and let the two areas be viewed

through an aperture or separate apertures, and the match at once becomes much less difficult.

Radiation falls on obstructing surfaces at various angles. These varying *angles of incidence* determine the amount of reflection and, as a result, function for the observer as factors in seeing various degrees of lightness. In addition, the different amounts of reflection from different parts of a surface enable the perceiver to see a third dimension and objects with volume.

Illumination of an area in the visual field may be intermittent, as when one looks at a revolving fan. Its blades intermittently obstruct and permit a view beyond them. Radiation falling on them and reflected to the observer produces what is seen as a film, through which objects are observable beyond. There need be nothing about the visual properties of this film to indicate that it is being produced as it is. A sheet of glass with a thin layer of dirt or paint might produce the same visual effect. It is this ambiguity regarding the nonvisual reality of the situation that emphasizes what Ames (1946) has pointed out, namely that perception possesses the nature of a bet or mere prognostication. In some situations the probability of the bet is high: The likelihood that nonvisual reality will be in accord with the visually perceived reality is high. In other cases, the prognostication is poor. If, in the case of the fan, the observer reached out to try to touch it, the poorness of the prognostication would be amply demonstrated, for the individual would get his fingers nipped. Visually, the film is perfectly innocuous; tactually, it is a very different matter. Touching the "film" is like touching a buzz-saw in motion.

In some respects, interrupted radiation functions essentially the same whether a beam from a radiation source is being interrupted or whether reflections are interrupted, as in the case of the moving fan blades. The ratio between the period of interruption and the period of transmission or reflection determines the quantity of radiation reaching the eye in a given period and thus determines the lightness or brightness seen. A film, however, is produced only when the radiation source is on the same side of the moving blades as the observer so that there can be reflection.

Constancy and the perception of illumination

In Chapter Four, it was pointed out that under some conditions the perceiver is able to make a distinction between the properties of a target surface and the photic illumination it receives. MacLeod (1932, 1940) pointed out that we must not conclude that the perception of illumination as such is an essential condition for the operation of color or lightness constancy. He and a number of other investigators look upon the perception of color and lightness constancies and the perception of illumination as two products of some more fundamental factor. Very definite constancy

phenomena can be produced that are not dependent upon the perception of illumination.

Shadows

Long ago, Hering pointed out that if a black line is drawn around the edge of a shadow, the shadow as such will disappear. The shadow area will take on the appearance of a dark surface. This fact was used by Kardos (1934), who used an encircled shadow with a small disk at its center to show that when the shadow is encircled the disk appears darker, in contradiction to laws of color contrast that would be expected to operate in this situation. He also found that the effect was relatively independent of the area of the field and would occur as easily with a white encircling line as with a dark one. Thus, one cannot use the line as a factor in the explanation by saying that it produced a lightness contrast effect. The preferable explanation is that conditions that produce shadows make them operate as special forms of local illumination. Accordingly, the disk shifts toward greater lightness in line with the laws of lightness constancy. When the shadow is turned into a surface, it is seen as darker. Whatever the explanation may be, the change from shadow to surface color in the Kardos experiment is not to be doubted.

MacLeod (1940) repeated Kardos' experiment in the following manner. A circular white line 5 millimeters in width was placed on an upright surface seen as black. A circular shadow was cast so that its penumbra coincided with the line. (A penumbra of a shadow is its tapered or less-dark outer border.) In MacLeod's setup the area was seen as a luminous black surface bordered by a white line. The area looked like a piece of velvet or like a black hole cut in a surface. When he shifted the surface on which the shadow fell to dispense with the white encircling line, the area simply became a shadow and was not so dark as it was to begin with.

In the center of the shadow, a rotating disk whose two components, "white" and "black," could be manipulated was introduced. Consultation of Fig. 6.2 will help to understand the setup. Two disks, C_1 and C_2, are propelled by motors that lie behind screens of low reflectance (black). A is also a low-reflectance surface. E_1 and E_2 are shadow-casters for the radiation source D. The observer is O, and views the setup through aperture F.

When observers were given the chance to observe the visual field produced by the foregoing conditions, they found it quite difficult to say what was what. The shadow cast by E_1 was encircled by the line already mentioned; the shadow cast by E_2 was not. In every case, the encircled shadow and its central disk were perceived as definitely darker than the comparison target formed by the shadow of E_2 and its disk. The unencircled shadow was more difficult to localize in distance. In other cases, the shadows were seen as being at different distances.

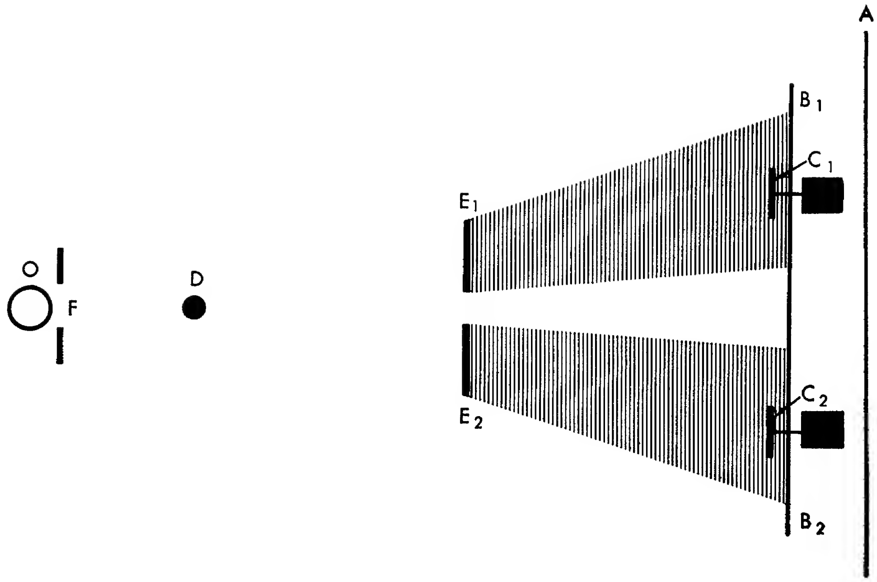


Fig. 6.2. MacLeod's arrangement for studying lightness constancy. A is a uniform low-reflectance surface. B_1 and B_2 are low-reflectance cardboard screens. C_1 and C_2 are color wheels. E_1 and E_2 are shadow-casters. F is an observation window. O is observer's eye. D is a radiation source. (R. B. MacLeod. Brightness constancy in unrecognized shadows. *J. exp. Psychol.*, 1940, **27**, 1–22, Fig. 1.)

About 60 percent of the thirty-eight observers perceived no special or anomalous illumination. The summary of findings for the experiment as a whole was that (1) a definite difference in lightness was described for the two targets even when neither one of the two shadows was perceived as shadows and (2) the difference remained despite full explanation of the setup to the observers.

It would seem that MacLeod showed that the perception of anomalous illumination conditions does not lie back of all lightness constancy results. MacLeod concluded that the phenomena in question could be handled better by referring them to organization of the visual field and that the concept of "constancy" is of doubtful value in studying such situations as illustrated by the present investigation.

MacLeod's conclusions are in contrast with the usual "cue" explanation of the nature of visual perception. It will be recalled that elsewhere the fallacy of prevalent cue theory has been pointed out, for it consists in using one perception to help explain another when the very same stimulus field is responsible for both of them. Here, in the case at hand, MacLeod has shown that lightness constancy has not depended upon the "cue" of illumination.

Contributions of the perceiver

In many experiments in lightness constancy, and in the other forms of constancy as well, all observers do not see alike. This divergence reminds us that the observer brings something to the occasion; sometimes it is labeled *past experience*, sometimes *set*, sometimes *attitude*, sometimes *knowledge* of the situation. None of these labels is descriptive of the actual mechanisms at work, but they all do indicate that the observer is not a fully neutral or passive system that is acted upon from without. Certain predispositions of the observer have to be taken into account here as in every case dealing with perception. Just what weights the stimulus conditions and the predisposing factors within the observer have must be determined by experimentation. From appropriate experimentation some sorts of generalizations are to be expected. Much more work is necessary for us to arrive at desirable ones.

SIZE AND DISTANCE CONSTANCY

In size constancy, we deal with the ability of the observer to perceive metric size ("true" size, or the size determined by using a meter stick) regardless of target distance or other factors that might be expected to interfere. Metric size of target and the awareness of the observer that the object constitutes a smaller and smaller part of the visual field as its distance from him increases, must be distinguished.

All visual targets subtend visual angles, small or great. Certain distant large targets subtend the same visual angles as certain near small ones. The visual field need not be structured for an object to be seen at a given distance; but when it is structured the field largely determines the distance at which the object is seen. In keeping with this field structure, objects are likewise seen as metrically small or large. To perceive size in this way is something different from noting analytically that the portion of the total visual field occupied by the object is small or large.

An object may be seen as a familiar object, as a tree, a playing card, a thimble, and so on. When it is seen as a member of a class of objects whose range in size is rather limited, it is seen also as a large, medium-sized, or small object of its kind. One aspect of the perception of the object is *identification* and the other is *appreciation of size*. Some persons who attempt to explain perception of size use identification as a crucial factor. It will be recognized that this principle has been discussed before as a logically unjustified procedure, for it makes one aspect of perception explain another. The two aspects are but two end results stemming from a common origin, and in order to account for them the common origin must be discovered. It is a slightly different procedure, however, when a contribution of the organism other than perception is taken to be a crucial factor in producing a perceptual end result.

Perception of object size follows one set of laws in an unstructured field and a different set in a structured one. This is to say that when the object in question is the only thing in the visual field, the field contributes nothing to object identification. Hence, from the stimulus standpoint, broad field properties cannot be called into use. The only thing that is structured is the small region that constitutes the object itself. This leaves the object to be almost any size. Lack of field structure leaves object location indefinite also. The object may be near or far away. Despite this indefiniteness as far as stimulus contribution is concerned, the observer does not fail to perceive. What has happened is that the organism itself has had to put more into the matter. The organism simply acts as though one of the several alternatives were true. Perception proceeds as though a choice had been made, as though a premise had been used or an assumption had been instantly employed. We do not know what the process actually is. We only know that perception proceeds *as if* the above were true. No marked delay, no antecedent conscious process, takes place. Perception is just as straightforward as though the stimulus situation had furnished all the determinants necessary.

The laws that govern visual perception of size when the field is structured stem from the field itself. The most fundamental and comprehensive description of the visual field is Gibson's texture-gradient concept, which he uses to describe three-dimensional space perception. For this the reader is directed to Chapter Seven. Here it can be said only that the visual field is conceived as existing as a textured expanse. The texturing of the field is of such character as to determine the distance factor of perceived objects (segregated portions of the field) as well as their direction and size. Thus, according to this view, one must not confine his search for the controlling factors of object size to the characteristics of the object itself. That is, no restricted portion of the field possesses the necessary and sufficient factors for size determination; the field as a whole must be taken into account. The contribution of the observer which varies in its influence, must also be taken into consideration.

Size constancy and great distance

The perceived size of an object does not diminish in keeping with the retinal image of the target as it recedes in the distance. Few persons suppose, however, that the perceived object size does not diminish at all when the target is placed at great distances. At certain distances the target subtends visual angles so small that the object is scarcely visible. It is then that the second of the two above-mentioned modes of perceiving size comes into prominence. Size now may come to mean the occupation of an insignificant portion of the total visual field; extremely small size and bare visibility may now become synonymous. Before this happens, the object might very easily

be supposed to be becoming smaller. Size constancy is generally thought to break down for targets removed to great distances. For targets outdoors in contrast to those in rooms, apparent size would be expected to taper off long before disappearance into the horizon. This general outlook on size constancy was investigated as follows.

J. J. Gibson (1950) exposed upright stakes in a flat unfurrowed field, one at a time, at various distances. The stakes ranged from 15 to 99 inches in height. A row of comparison stakes was set up at a little distance from the subject at right angles to his line of regard. Each was of a different size, and the stakes were numbered 1 through 15. As a distant test stake was exposed, the observer was to indicate with which of the sample stakes it compared closest in height. The observer could even say "smaller than one" or "taller than 15." No preclusion was made for range in perceived heights.

The trials included different sizes of stakes at different distances in random combinations. Each observer made 150 observations. Averages of the perceptions were computed for the different stake sizes, distances, and observers. Let us look at what the observers did in perceiving a 71-inch stake, the one that compared to comparison-stake number 12. At 42 feet, the mean perception was 71.9 inches with a standard deviation of 1.8 inches. At 672 feet, the mean perception was 75.8 inches with a standard deviation of 7.3 inches. At nearly half a mile (2352 feet), the mean result was 74.9 inches with a standard deviation of 9.8 inches. For four other distances the results were comparable. Since at one-half mile, the 71-inch stake was almost invisible, but was still perceived just about as nearly correctly as stakes much nearer, the question of diminution of size constancy with distance is answered. Distance has essentially little to do with size constancy. The object remains its "true" size just so long as it can be seen at all. On the other hand, something else happens to the perception of distant targets: The heights of the stakes become more and more indeterminate as distance increases. This is evidenced in the increase in variability of reports as distance increases.

Gibson and Henneman (Gibson, 1950) investigated the perceived size of targets and distances between them in a thoroughly cluttered room. The results indicated that size constancy for objects and constancy for perception of distances between them followed the same principles. Thus it can be said that the same concept of constancy applies to interobject distances and object dimensions. This would tend to lead us to conclude that constancy is a field property rather than simply a *thing* property, thus obviating the need for special explanations for constancy based on some uniqueness in perceiving objects. It is easier to comprehend how a part of a field is subject to the principles that govern the field than it is to understand how field items obey laws of their own in isolation. It does not seem appropriate to resort to mysterious intrinsic properties or to cues with all the logical objections we have pointed out as applying to them. Consideration of total

sets of factors acting in organized ways is also more appropriate than reliance solely upon the "contributions of the observer" in the form of learning and past experiences.

Size perception in an unstructured field

We have already mentioned that size perception in an unstructured field is different from that in a structured one. In fact, it is so different that certain experimenters disclaim the virtue of using unstructured fields for the study of any of the features of perception. As we have pointed out, however, it does demonstrate the fact that perception is possible when little is given by the stimulus. Although it can be shown that the organism is so constituted that it can proceed somewhat on its own, we cannot as yet be sure of arriving at many laws regarding just what direction perception will take under such field conditions. As one example of perception in an unstructured field, the following card demonstration is given. If a target comprising a rectangular blank card is the only visual differentiation provided in a dark room, it may be perceived as almost any size. It may be seen as a small rectangle nearby or as a large rectangle far away. Both may produce the same-sized retinal images. Since it is only the retinal image and the contribution of the perceiver himself that determine the perceptual end result, object size is dependent upon the *distance* at which the object is projected in perception. Size and distance are reciprocal for any fixed retinal image. The observer sees the object as a certain size and at a certain distance. All that we can show is that the two are related to each other, as would be expected from the trigonometry involved in target size, target distance, and the retinal image produced. The pivotal factor is retinal image size, for that is the only fixed thing as far as the stimulus is concerned. If a playing card is substituted for the blank card, then one more of the factors becomes determined: The observer "knows" the size of playing cards. Thus, with retinal image size fixed—the object size fixed—distance is determined. The object seen can be seen at only one distance, unless it is possible to conceive of giant playing cards and miniature ones. A rare observer may be able to act as though looking at a giant playing card; if he does, its distance from the observer is increased. Or he may be able to act as though looking at a miniature; if he does, its distance is diminished. Nevertheless, the experimenter cannot obtain these results by merely asking all observers to "imagine" that the cards are giants or dwarfs. The more facile observers may be able to do so, but most of them may not be. Likewise, the experiments can never predict when some observer is going to see something in a way all his own. All we can say is that what he does is lawful. The fact that the observers have this latitude is the troublesome thing. We cannot tell when some new factor will enter, and we cannot always control the factors we intend to.

We are now ready for another indoor example of size constancy. Holway and Boring (1941) compared two circular targets, one fixed in position and the other posed at various distances. The stationary target was 10 feet from the observer; the movable one varied from 10 to 120 feet. The stationary target was seen as a disk of light the diameter of which was controlled by an iris diaphragm. The movable target was adjusted so as to subtend a visual angle of 1° at each position used. The observer's problem was to adjust the stationary target in diameter so that it appeared to be the same size as the movable target whose diameter was kept at 1°.

The Holway and Boring investigation approaches the tests for the "law of the visual angle" and the "law of size constancy" by using the stationary target to represent the apparent size of the movable target. The angular subtense (at the eye) of the diameter of the movable target was held at 1°. The movable target was thus made larger and larger as it was moved away from the observer. The diameter of the stationary target was adjusted so that the two targets continued to seem equal in size. This operation should disclose which of the two "laws" or rules operates or whether the results turn out to be a compromise. If the stationary target can remain unchanged in diameter, then the law of the visual angle is demonstrated because both targets, in all cases, subtend the same visual angles (Fig. 6.3). If the diameter of the stationary target must be changed as the movable target is placed farther and farther away, then the law of size constancy is demon-

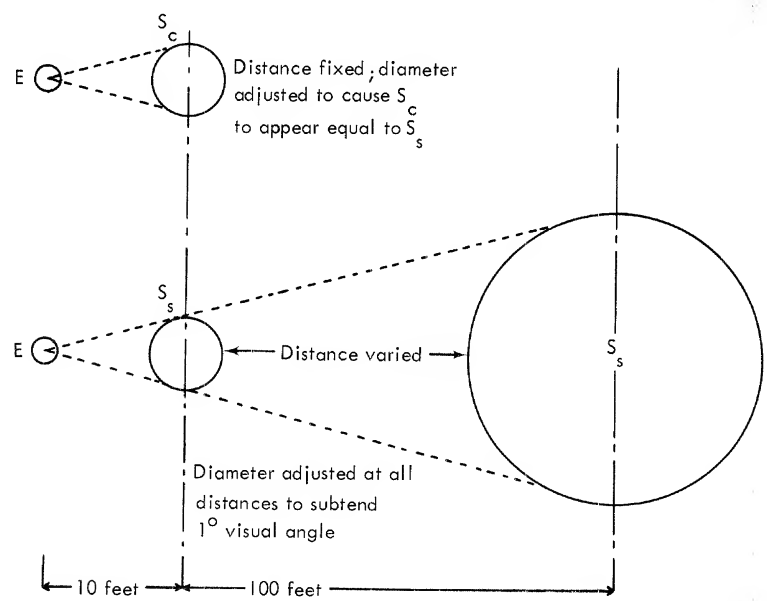


Fig. 6.3. Stimulus conditions in the experiment of Holway and Boring (1941).

strated. Both targets are made equal in size regardless of difference in distance and, thus, regardless of the visual angle they subtend at the eye.

The two laws represent the opposite extremes that the results could represent. If as in Fig. 6.4, the diameter of the comparison target is repre-

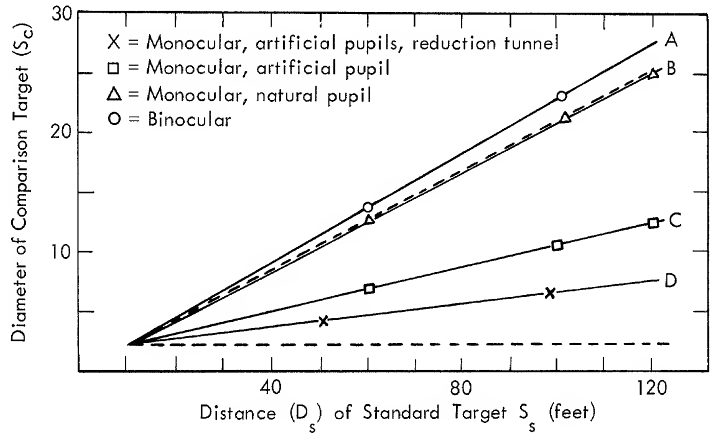


Fig. 6.4. Relation of diameter of comparison target to distance of the standard stimulus for the conditions in Holway and Boring's (1941) experiment. The diagonal dashed line shows expectation of size constancy. The horizontal dashed line shows expectations according to the law of visual angle. Curve A is for binocular viewing, B for monocular with natural profile, C for monocular with artificial pupil, and D for monocular with artificial pupil and reduction tunnel. (C. H. Graham. Visual perception. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951, Fig. 2.)

sented on the vertical axis and the distance of the movable target is represented on the horizontal axis, the relation of the results to the two extremes represented by the laws can be shown. In the figure, the horizontal line expresses the law of the visual angle since the movable target is adjusted to subtend constant visual angle regardless of distance. Accordingly, the diameter of the fixed target must remain constant so as to match it, and the line in the graph must be horizontal. The broken sloping line represents the law of size constancy.

Holway and Boring found neither extreme to hold in their study. Four different observing conditions were employed. The results are shown in the four curves in Fig. 6.4. The lowest of the four sloping curves represents the results of one-eyed viewing with an artificial pupil and a reduction tunnel to eliminate the operation of certain extraneous field factors.

Obviously, monocular viewing eliminates stereoscopic factors and should work toward the perception following the law of visual angle. With

binocular viewing—that is, with conditions in which stimulation is least simplified—the law of size constancy is expected to operate most forcefully. In one condition, namely for unrestricted binocular viewing, the relation went beyond the constancy values (see curve A). For monocular viewing with natural pupil (B) an approximation to size constancy resulted. Under two conditions, the results were a compromise. The two compromise conditions involved certain limiting viewing conditions, such as monocular viewing with artificial pupil (C) and also with reduction tunnel (D).

Several other investigations are relevant. Although they were not conducted as studies of size constancy, they illustrate the fact that apparent size is not strictly determined by the visual angle subtended by the target. They show that although one may hold visual angle constant, apparent size may change. This is the other side of the general topic we have been discussing, which actually covers not only the cases in which the sensory end result remains constant in spite of some change in the input to the sense organ but also the cases in which the sensory end result changes despite the angular subtense of the target remaining the same.

The moon "illusion"

The fact that the moon looks considerably larger when seen near the horizon than when seen higher in the sky has interested men since at least the days of Ptolemy. He thought the effect was due to the observer seeing the sky as a flattened dome; the dome (seen as a surface) would be nearer the eye at the zenith than at the horizon and, therefore, the moon would seem larger when farther away. This explanation did not convince a series of more recent investigators, including Boring (1940a) who, with Holway, had studied the matter. They related the effect to the position of the eyes in their sockets. They believed that they showed that when the eyes are elevated in their regard, the object seen is smaller than when the eyes are in their normal positions. Following the study of Holway and Boring, the matter rested for a time. Since then several other investigators have studied the "illusion."

Kaufman and Rock (1962a) studied the illusion by projecting artificial moons against the sky at different elevations and they found that these targets looked larger when near the horizon. They showed that the effect could not be understood in terms of an egocentric reference involving moon positions in relation to gravity.

It is known that the perceived moon differs in color at the horizon and high in the sky. The question of whether this might have a bearing on its perceived size was studied, but they found no evidence that color changes had any bearing on perceived size. They also studied the brightness of the moon and found no effect. The dimmer appearance of the full-horizon moon is a concomitant of its apparent size.

Kaufman and Rock obtained as part of their study judgments of distance of the sky without regard to any seen object such as the moon. They asked observers to scan a moonless sky and attempt to see it as a surface and report whether the surface seemed farther away at the horizon or at the zenith. Nine of ten observers reported that it was farther away at the horizon.

Another supposition tested was that the illusion is dependent upon the presence of terrain between the moon and the observer. They manipulated the terrain factor by artificially putting the terrain high in the visual field rather than in its normal position below the horizon. From their results they believed the presence of terrain (a field structure) was crucial for obtaining the usual moon illusion.

A more recent study related the moon illusion to the well-known rule in visual perception called Emmert's law, which arose from the study of afterimages and states that the apparent size of an afterimage is directly proportional to its apparent distance from the observer. Afterimages can be projected onto surfaces at various distances and, when projected onto a surface, they become a part of it. When that surface is at a distance, the afterimage is larger than when a part of a nearby surface. King and Gruber (1962) trained observers to obtain afterimages of presented targets and to project them onto the sky at various controlled elevations. It was found that the afterimages were seen as larger near the horizon than at the higher elevations in the sky. King and Gruber used Ptolemy's supposition that the sky is seen as a flattened dome. Monocular sighting was used and the effect was obtained with it for all but two observers; binocular sighting was successful for these two subjects. Kaufman and Rock had failed with monocular sighting in their experiment.

Of the sixteen subjects in King and Gruber's work, eight were tested with a cloudless sky, five with a sky with a few "wisps" of clouds, and three with an overcast sky. These conditions produced no difference in results.

The studies seem to show that what we could call contextual factors or field factors do have effects. Whatever the field factors are, in this general situation they result in the observer seeing the sky as a flattened dome. The moon or the afterimage, as the case may be, is given a position in the space as structured and the object's size is consistent with it.

The whole subject is an illustration of the fact that sometimes our curiosities and, therefore, our approaches center about some restricted portion of the total visual field rather than the total. Here it was the moon whose subtended visual angle remained constant under all the conditions considered, but apparent size changed. Hence, why it changed was puzzling. As soon as the total field came into consideration, changes in it were immediately recognized and the sensory outcomes came to be understood as a function of such changes. This wiped out the illusory nature of percep-

tion, at least so long as the person refrains from considering the moon as an isolated stimulus input.

Hastorf's investigation

Hastorf (1950) performed a study in size perception that involved two fields of view. One was for binocular vision; the other was for only one eye. The binocular field was such as to give rise to seeing a three-dimensional situation with perspective and objects at several distances. The field for the single eye was completely unilluminated. In the darkness, all the observer saw was a disk or rectangle of light. The target that produced this could be varied in size. The consequent change in the apparent distance of the disk or rectangle could be indicated by its localization relative to the perceived items in the binocular field. The binocular field comparison items were four posts distributed at intervals of one foot.

The monocular field was a projection screen on which the disk or rectangular target already mentioned was projected. This screen was at the same distance from the observer as the third post in the binocular field. A Clason projector provided a target that varied in size without developing a consequent blur in contour.

According to the experimenter's instructions, the disk of light in one set of observations represented a ping-pong ball and in another set a billiard ball. In two different sets of observations, when the rectangle was used, it represented a calling card and an envelope, respectively. In all cases, the observers were to set the target (disk or rectangle) at a size necessary for the seen object to be at the distance of post number 3 in the binocular field while using the monocular and the binocular fields at the same time. The supposition was that the binocular field gave third-dimensional perception and could be used as an indicator for the distance at which the object was seen by the one eye using the monocular field. The readings compared pretty well to what would be expected from the visual angles that would have been subtended by the actual objects, that is, billiard ball and ping-pong ball. Since these balls are of different sizes, they required different adjustments of the target size.

In the third part of the experiment, the size of the target was not at the mean reading given for the ping-pong ball. The observer was then asked to locate the distance of the object seen, by telling where it was in relation to post number 3. Nothing was said about whether the target in this case was a ping-pong ball or a billiard ball, although it was a "billiard ball." The disk was reported beyond post 3, as would have been expected, for the target was too small to be at post 3 if the object was a billiard ball. Implied in the experimentation is the assumption that the observers would be still behaving as if looking at a billiard ball.

Implied in the behavior is the principle that behavior follows certain "assumptions" the observer makes. The investigator felt that he had demonstrated that there is something "assumptive" about perception that heretofore had not been well recognized or demonstrated. While this is not one of the more usual forms of investigation of size constancy, it does involve the continuity and constancy principles.

Summary

The foregoing examples of the very best work in the study of size constancy show that field properties, eye posture, and the "contribution of the observer" work in curious combinations from situation to situation and are not all of the same weight or even present in all situations.

SHAPE CONSTANCY

The third aspect of constancy is shape, which enables us to identify objects or distinguish them from each other. Shape as pertaining to objects and shape as descriptive of the various regions of the visual field are to be distinguished from each other. For example, we perceive the top of a table as rectangular and say that shape belongs to the table. Rectangularity is ascribed to the table top regardless of its position with regard to us. On the other hand, we know that the "shape" presented to the eye may be any one of an infinite number of shapes, depending upon the table's position. Obviously, perception is involved in distinguishing the shape of the table top from the shape of that portion of the visual field segregated off as table top. Were the perceiving organism unable to make this distinction, it could not react as it does. It might act as though the visual field was a single plane, the frontal plane, with all events occurring within it. Thus, if we were to present such an organism with a three-dimensional table top and tip it in various directions one after the other, the organism would not see a single entity being moved about in three-dimensional space but would see a region of a two-dimensional field continually changing shape. If this continually changing of shape were seen as a single entity, it would be credited with being quite elastic or pliable rather than rigid, as we now see table tops to be.

It is operationally convenient to distinguish between shape in a two-dimensional geometry and a three-dimensional one. Even so, two-dimensional shape may involve one or more orientations from occasion to occasion in three-dimensional space. As an initial but not a final label, we may speak of this shape as *real shape*. It is only real in the sense that perception makes it have continuity and assigns it to an object. We must also consider shape in the frontal plane; we can call it a frontal plane projection of real shape. From Fig. 6.5 it can be seen that the tilted target makes an image on

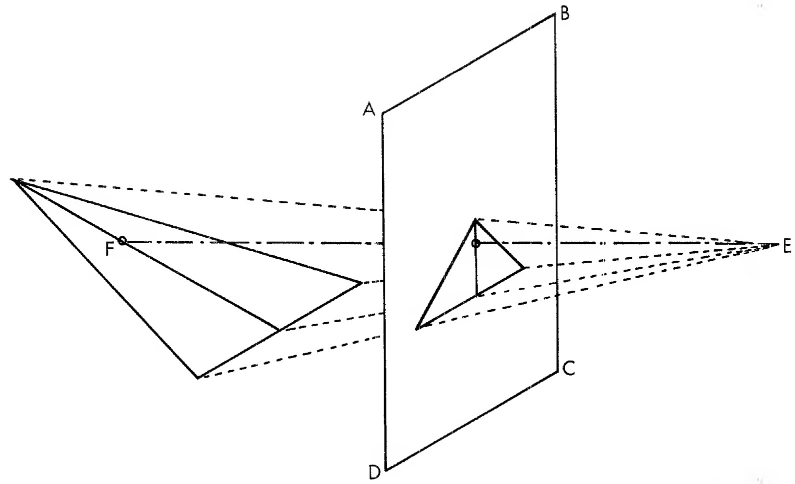


Fig. 6.5. Frontal plane projection. E represents the eye and F the fixation point on a tilted triangle. ABCD is a frontal plane with respect to the eye, which is to say a plane at right angles to the line of regard, EF. Imagine the frontal plane to be a plate of glass. Projection lines from the corners of the triangle to E would intersect the glass as indicated. If these points were connected, a triangle would be formed whose shape would represent the shape of the original triangle projected onto the retina.

the retina as though it were another target in the frontal plane instead of the target it is. For convenience, all targets may be referred to the "projection" they make in the frontal plane. We may say that the frontal plane projection of a circle, when tilted out of the erect position (more strictly, tilted out of the frontal plane), is an approximate ellipse. Actually, in some cases, as we shall show later, the perceiver cannot tell whether what he sees is an ellipse in the frontal plane or a circle tilted out of the frontal plane. This general principle should be kept in mind throughout our discussion of shape constancy.

It must be understood also that targets in this sort of study are described in terms of Euclidean geometry, about the best distinction between stimulus specifications and perceptual specifications we are able to make. There are times when a Euclidean term as "square" or "triangle" is unfortunately both a geometrical and a perceptual term. We have pointed out in several other connections that it is necessary to try to have a language that pertains to details of perception, but the point must be reiterated here. It is easy to think of real objects in terms that are only descriptions of perceptions: The nearest we can come to describing external reality, the targets used, is to indicate their geometrical properties. This is a compromise

or a descent from the ideal of specifying spatial factors (or whatever they may be) in wholly nonperceptual terms.

Regression to the "real object"

A good place to begin our discussion of shape and shape constancy is with Thouless' (1931) work. His very first study consisted in presenting observers with a disk target and a square target. One or the other was placed on a long table and viewed obliquely by the observer from a fixed viewing position. Obviously, as the position of the target was shifted farther and farther out along the table, it was viewed more and more obliquely. Obliqueness of view produces a retinal image shape different from that of the normal view (at right angles to the plane of the target). Thouless called the target the real object, R. The resulting retinal image, with its varying shape in relation to obliqueness of viewing conditions, he called the stimulus object, S.

As observers we can deal with targets in two ways: we can identify them as objects or we can deal with some object property, in this case the property of perceived shape as abstracted from identity. In Thouless' experiment, it was obvious to the observers that they were dealing with a disk and a square at different times so the identity of the "real object" was not at issue. Thouless wanted his observers to indicate the seen shapes as the targets were made more and more oblique to the eye (in Fig. 6.6, the target obviously subtends a much smaller visual angle at position 3 than at position 1).

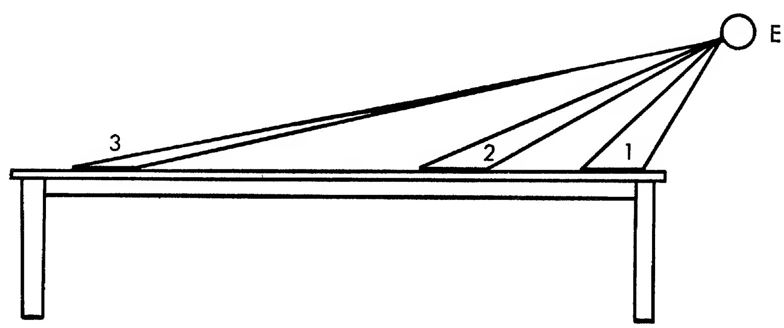


Fig. 6.6. Thouless' experiment. E is the eye. Items 1, 2, and 3 are the target positions. Shifting the target from one position to another changes its effective shape (frontal plane projection) and varies the visual angle subtended by one dimension.

He had the observers draw the shapes they saw. To indicate shape, he used a ratio of the short axis (vertical) to the long axis (horizontal) of the form they observed. Obviously the shapes the observers saw in looking

at the circular target obliquely were approximate ellipses. The drawings were measured in terms of the ratio and found to represent a seen shape (phenomenal shape) somewhere between the shape of S and the shape of R. This shape Thouless called the phenomenal object, P. To provide a numerical way of expressing the relation of P to R, he used the ratio

$$\frac{\log P - \log S}{\log R - \log S}$$

He called this the index of phenomenal regression. He labeled the perceptual behavior "phenomenal regression to the real object." This implies that there is some fixed intrinsic entity called the real object and that it has some influence upon what is perceived. We are hard put to conceive of the real object meant here as being anything other than either a (1) concept or (2) perceived object to which the perceiver is led to attribute a more ultimate form of reality than the perception of shape referred to the frontal plane. What reaches the eye is a pattern of photic radiation that corresponds to the shape (the geometry of S), whereas R is both a perceptual object and a conceptual one. Thouless is assuming that whatever gives rise to the experience of circularity or squareness, regardless of the angle of viewing the target, is the real object, something that has some uniqueness and indestructibility.

Some other sorts of investigations involve conditions through which a further look at the idea of real object can be had. Several investigators have used targets in unstructured fields: the targets were luminous and the only observable items in a dark room.

Further experiments

Nelson and Bartley (1956) used three such targets, luminous wire forms, a circle and two ellipses 4 by 5 inches and 3 by 5 inches. These were oriented in several positions: (1) in the frontal plane, that is, upright; (2) at a 22.5° tilt from the vertical away from the observer; (3) at a 45° tilt; and (4) at a 67.5° tilt. There were twelve different kinds of presentations given in random order. In the graph in Fig. 6.7, the phenomenal or perceived shape is represented on the vertical axis and stimulus shape (or the shape of the retinal image) is represented on the horizontal axis. Were there a direct correspondence between the two, the results would fall on the diagonal straight line. Nelson and Bartley used the same kind of notation as in Thouless' investigation and likewise obtained the data through observers' drawings. It will be noted that the data cluster somewhat along the line. This is to be interpreted that in general the observers behaved as if they saw all the targets in the frontal plane, since it was the stimulus shape that was represented in the perceptions.

It cannot be insisted that the departures from perfect correspondence

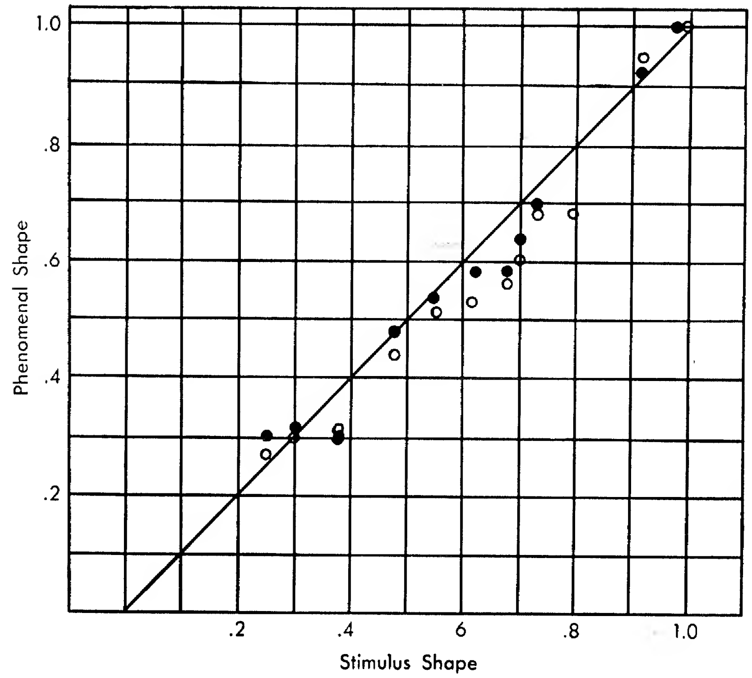


Fig. 6.7. Relation of observed (phenomenal) shape to stimulus shape in an unstructured field. Shape in both cases is measured by the ratio of the vertical to the horizontal dimension. (T. M. Nelson and S. H. Bartley. The perception of form in an unstructured field. *J. gen. Psychol.*, 1956, **54**, 57–63, Fig. 1.)

to S in the data are slight regressions to the real object. The "real objects" (the targets) in this investigation were not always circles, and they were not always what Thouless defined as real. One would not know which real object to refer the data to.

It will be remembered here that a target forming the same given retinal image may be an ellipse or a circle, for a tilted circle will involve the same "projection" in the frontal plane (that is, the same visual angle) as a certain ellipse. It is obvious that the observers had no way of "knowing" which was the case in any trial. They could have seen the target as either one for one would have made as much sense as the other. The twenty-four observers never acted as if they saw tilted circles.

In Fig. 6.8 is another set of data for observer behavior with ellipses and circles at various tilts, taken from the work of Miller and Bartley (1954) in which the field was structured. In this case, the targets were cardboard circles and ellipses placed on a tilt board whose limiting edges were hidden by a reduction screen (Fig. 6.9). It will be noted that from this lighted-

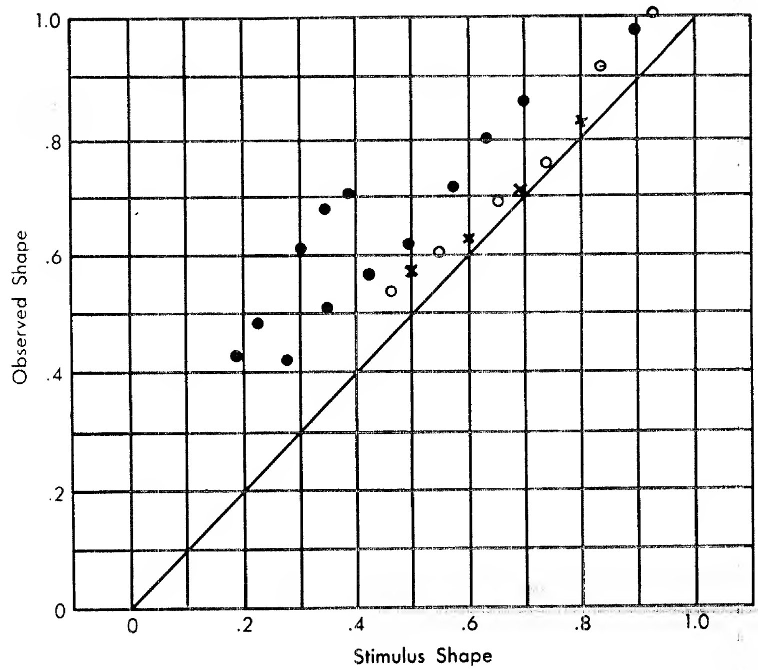


Fig. 6.8. Relation between observed shape and stimulus shape in Miller and Bartley's experiment, to be compared to Fig. 6.7. (T. M. Nelson & S. H. Bartley. The perception of forms in an unstructured field. *J. gen. Psychol.*, 1956, **54**, 57–63, Fig. 2.)

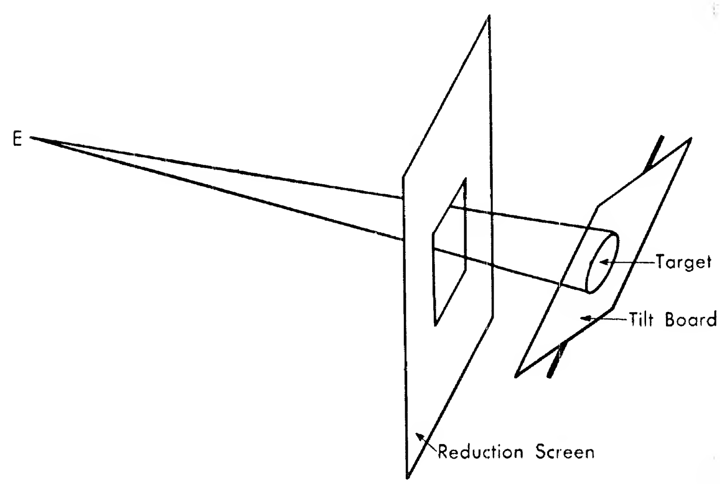


Fig. 6.9. Arrangement in Miller and Bartley's (1954) experiment in which a reduction screen prevented the observer at E from seeing the edges of the tilt board.

room experiment the perceptions were much different from those obtained in an unstructured field. The phenomenon that Thouless called "regression to the real object" seemed to be involved. But since there were several "real objects" and since the observer had no way of "knowing" what the targets were like, the concept of real object is not a suitable one. In this experiment there were five ellipses and one circle presented in four different positions (one erect and four tilted). Even this investigation began to demonstrate that the concept of real object has limited usage in dealing with perception of shape and shape constancy. The findings obtained in an unstructured field make it even more obvious that the real object, as an indestructible entity existing outside the observer and describable in perceptual terms, is a fiction. We do possess concepts of objects, such as circles, diamonds, triangles, and so on. We are impinged upon by certain photic energies and we do see objects tallying with our object concepts. But in trying to understand visual perception we cannot begin with the idea that there are real objects, outside of the experiences we have, and that they have some peculiar influence upon perception. The real objects lie within our perceptions.

Perception of tilt

Another type of observing problem needs to be discussed: the task of reporting upon perceptions of tilt. For this we shall consult the findings of Haan and Bartley (1954). In their work, the same stimulus conditions were used as in Nelson and Bartley's (1956) study. In this case, however, the observers were asked to report on perceived tilt. In Fig. 6.10 the phenomenal tilt (perceived tilt) is plotted against stimulus (target) shape. The three solid curves beginning at the upper left and descending toward the lower right represent the cosine functions for various shapes (minor-major axis ratios) in relation to actual tilt. In other words, the lefthand curve represents the cosine function for an ellipse having a 3-by-5 shape; with no tilt from the vertical, such an ellipse presents a 3-by-5 shape (0.6). When the ellipse is tilted a full 90° from the perpendicular, it presents a zero shape. The middle curve represents a 4-by-5 ellipse (0.8) and the righthand curve represents a full circle (5 by 5, or 1.00).

The first thing that can be said about the findings is that most of them lie between the limits expected of a 3 by 5 ellipse and a full circle. But to the question of what is the real object functioning in the experiment there is no sensible answer except to say that whatever the observer sees is real—real to him—and that there is no other necessary single reality toward which perception must regress. Here again we see that the concept of regression to the real object does not apply, and if used at all it has to be confined to Thouless' investigation or some other like it. In this connection, it may be stated that in the Nelson and Bartley experiment, telling the observers that the objects were circles at various degress of tilt, when

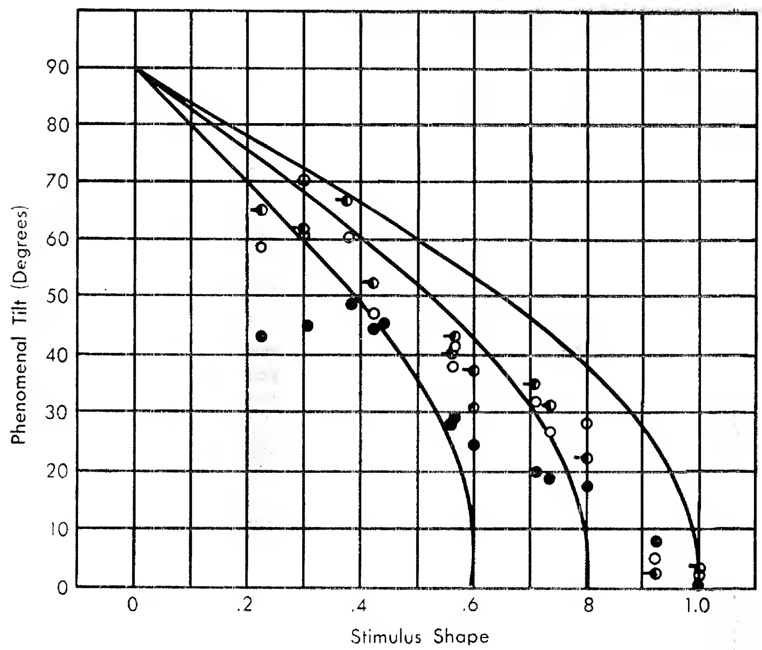


Fig. 6.10. Relation between stimulus shape and phenomenal tilt. Shape is defined as the ratio of the vertical axis to the horizontal axis of the stimulus. (E. L. Haan & S. H. Bartley. The apparent orientation of a luminous figure in darkness. *Amer. J. Psychol.*, 1954, **67**, 500–508, Fig. 1.)

asking for shape reports, influenced shape very little. Of course, it could not be ascertained how thoroughly the observers were made to "believe" that the targets were "circles," but at least the potential bias was offered, and it did not make much difference in that particular experiment.

Invariance

Invariance is a concept closely related to constancy but up to now it has not often been discussed in connection with it. Invariance refers to a lawful relationship between two items. It is, in effect, the opposite of irregularity. As one tilts a plane target backward from the vertical or frontal plane position, progressive obliqueness causes it to subtend a smaller and smaller visual angle until it subtends virtually none when viewed as merely the thickness of the target. This diminishing vertical dimension is described by the trigonometric function, known as the cosine function.

We have been speaking in "physical" (geometric and trigonometric) terms. In psychology there is a second set of items called the phenomenological (or perceptual). Invariance, then, can be posed in several ways. Is there invariance between physical and perceptual factors, or is there

invariance between the two sets of perceptual factors shape and slant? We already know that there is invariance between the geometrical factors.

Let us cite the invariance study of Nelson, Bartley, and Bourassa (1961) on the effect of area characteristics of targets on shape-slant invariance. They believed that there is good reason to suppose that what is seen as shape is influenced by the characteristics of the areas bounded by the borders of the targets.

Orbison (1939) had much earlier shown that protrusion of various features of field structure into the area bounded by an outline may affect seen shape. Reasoning from this, one might expect seen shape to vary not strictly with geometry but as a function of the degree of differentiation within the area bounded. Evaluating the effect of this differentiation upon shape for theoretical purposes involves what the observer sees as slant, and the distinction between psychological (perceptual) items and physical (geometrical) items must be observed. When one studies the relation of shape and slant as perceptual variables, he finds an invariance—that is to say, he finds a lawful relationship. However, if the perceptual entities are used along with a mixture of the perceptual and physical, invariance is departed from (Koffka, 1935; Stavrianos, 1945; Langdon, 1953; Beck and Gibson, 1955; Clark, Smith, and Rabe, 1955). Koffka's (1930) is the best-known statement of the belief that geometry and perceptual processes should tally. Stavrianos' (1945) investigation is the best example to show that they do not.

Nelson, Bartley, and Bourassa's (1961) study is a criticism of the idea that man's perceptual discriminations involve invariance relations similar to those ascribed to the world by Euclidean geometry. In the study, luminous targets were presented in an unilluminated field in which they were the only visible items. Four series of targets differing in internal differentiation (or "texture") were used. Each series contained twenty targets of different inclination and geometrical properties. They varied from a circle to ellipses 5 by 4 inches, 5 by 3 inches, 5 by 2 inches, and 5 by 1 inches. The orientations (or inclinations) were inclined 22.5°, 45°, and 67.5° from vertical (0°). One series of targets was wire outlines, another series was of untextured surfaces, still another possessed fine textures, and a fourth had course textures.

The task of the forty observers in part I of the experiment was to reproduce the seen slant of the targets by adjusting a tilt board to match what was seen. In part II, the observers were asked to draw the shapes of the objects seen. Shape in the study was defined as the minor-major axis ratios of the drawings.

For the outline targets, the invariance was virtually linear for the entire shape-slant continuum. The curves for the other conditions departed from this linearity to different extents, especially in the segments of the curves depicting large slants and small minor-major axis ratios. The departure from linearity was greatest for the course textured targets.

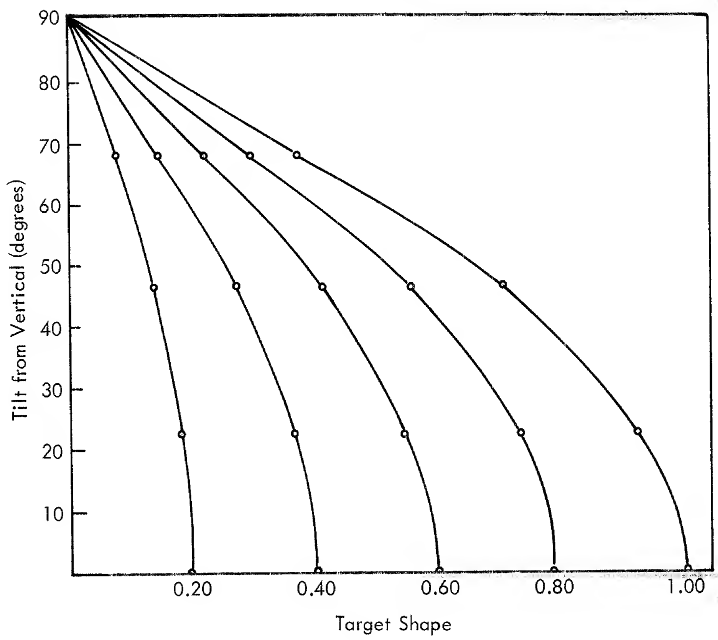


Fig. 6.11. Cosine functions of targets for various degrees of inclination. (T. M. Nelson, S. H. Bartley, & C. Bourassa. The effect of areal characteristics of targets upon shape-slant invariance. *J. Psychol.*, 1961, **52**, 479–490, Fig. 1.)

Figure 6.11 depicts the cosine functions for various target shapes (minor-major axis ratios) indicated on the abscissa. It will be seen that as such targets are tilted from the vertical each retinal image shape diminishes to zero according to the cosine function via its own parameters. Hence, there is a separate and different curve for each target.

When the visual (that is, perceptual) results are pictured, the relation between shape and slant is not according to the cosine function although it is lawful. The relationship (the invariance) was depicted by an entirely different set of curves (Fig. 6.12), already described. This is to say then that the family of perceptual curves in Fig. 6.12 does not seem to be determined by the variables attributed to the target by Euclidean geometry. One of the influencing factors is the surface characteristics.

We have already mentioned Stavrianos' investigation of shape constancy, or what might be called a test for shape-slant invariance, in which the geometrical and the perceptual factors were not kept separate. Her experiment consisted in having the observer tell which of a group of seven rectangles was seen as a square. The rectangles ranged from taller than wide to wider than tall. The surface carrying the rectangles varied from vertical to tilted 15°, 30°, 45°, and 55°. The observer was required to adjust a rectangle at his right so that its tilt appeared to be the same as the surface

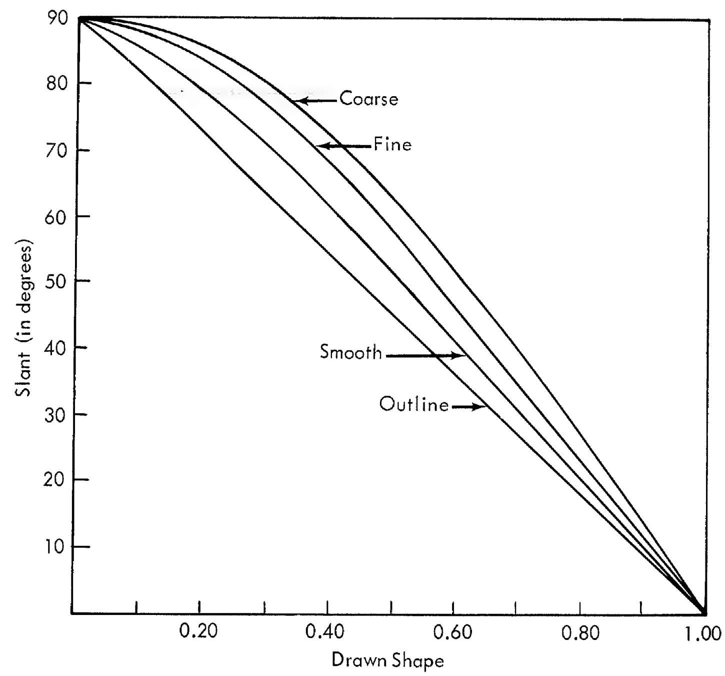


Fig. 6.12. Actual relations between target slant and drawn shape. (T. M. Nelson, S. H. Bartley, & C. Bourassa. The effect of areal characteristics of targets upon shape-slant invariance. *J. Psychol.*, 1961, **52**, 479–490, Fig. 1.)

carrying the group of rectangles. The observer was also to tell which of the rectangles was seen as a square. As the actual tilt of the standard increased, the comparison target deviated from it progressively in the direction of lesser tilt. Also the error in shape-matching increased as the tilt of the standard increased. With no tilt of the standard, the chosen rectangle was very nearly a square. As tilt became greater, the rectangle chosen as a square became a rectangle with greater and greater height in relation to width. In some respects Stavrianos' experiment showed the same principles as did the experiments of the other workers. However, there was a failure to corroborate some of the expectations made beforehand. One of these was to the effect that a reciprocity would exist between perceived inclination (tilt) and perceived shape. It is not certain that the most appropriate experimental conditions were set up to test this idea, so that failure in strict corroboration is not to be taken as final.

Two recent points of view with regard to the conditions for seeing slant are those of R. B. Freeman (1965a, b, 1966a, c) and Flock (1965). Freeman points out that with monocular viewing, visual slant and shape are a function mainly of linear outline perspective. The greater the magnitude of

linear perspective is, the greater is the perceived visual slant and the influence on judged shape. Flock believes that the assertion that slant is mainly a function of linear perspective is an oversimplification that does not quite cope with the facts.

Other workers dealing with texture include W. C. Clark and his colleagues (1956a, b) and Gruber and Clark (1956). Results vary with the conditions used and show that slant can be perceived when texture is absent and that under some conditions texture is less effective for accurate perception of slant than is target outline. All in all, the matter is too complex to allow for a full and adequate description here of the various conditions studied or even for a brief final statement of theoretical conclusions.

Goodness of form

Another prevalent concept is the idea of goodness of form, stemming from Gestalt theory. Some shapes are said to possess properties that others do not possess. By this is meant that, when stimulus conditions anywhere nearly approach the characteristics needed for the production of the perception of such a form, this form will emerge. It is as though the organism is prone to perceiving this form rather than just something somewhat similar. It is a difficult idea to test and substantiate and so it has not reached the status that have many other ideas in the study of shape perception.

While it is difficult to come to grips with the contribution of the organism in producing perception as we find it, it is nonetheless certain that the organism does contribute by ways of learned sets, alignments, expectancies, bias, and what not. Haan and Bartley (1954) introduced the concept of "assumed object" into the discussion of their study in line with what Hastorf's (1950) study of the relation of perceiving size and distance.

Operational aspects of perceiving shape

Certain aspects of the task of perceiving the shape presented to the eye or the frontal plane projection should be mentioned at this point. When a person attempts to draw just what he sees when he is looking at a tilted circular target, he is put into conflict. At one instant the most obvious feature of his looking is that he is looking at a tilted circle; the stimulus field is so structured that he perceives this with no doubt. If he is to picture on paper what he sees, he might even draw a circle, just as he would say that it is a circle. This act would be mere identification. But he not only sees a circle; he sees that it is tilted. How is he to picture that? Common experience has given almost every adult in our culture some information of how to approximate this. The ordinary person will draw a kind of rough ellipse. When not attempting exactness, he gets his task over within a hurry and with satisfaction. But if exactness is wanted,

the observer looks again and again, and each time he looks he is disturbed by not being able to break apart the necessary features of the situation. Instead of readily being able to see a frontal plane projection of the circle, he sees a circle tilted. It is *as if* he runs his eyes out along the surface of a tilted circle, and, before he knows it, what he is drawing looks on paper more like a circle than the required ellipse. Hence, we may say that the regression that Thouless talks about is actually something that accompanies seeing *tilt* as well as seeing a circle. The visual field is so structured that tilt and shape are bound together. As soon as field conditions do not lead to seeing tilt, the frontal plane projection can be represented on paper with not much trouble. Real objects, as something the experimenter presents as targets, do not exert intrinsic factors of influence upon shape perception.

COLOR CONSTANCY

Color constancy is the final form of constancy we will deal with. Much of what was said in Chapter Four and in this chapter on the other forms of constancy applies to color constancy.

General conditions of color attribution

The observer does not always know when he sees a surface whether spectral illumination or differential reflection is the cause of its color. The radiation may be from a restricted portion of the spectrum, or the surface of the target may reflect only the restricted band of wavelengths producing the color that is seen.

Cramer (1923) set up a situation that well illustrates this. He papered the walls of a corner of a room to produce a uniform color and then illuminated the walls by a concealed source of nonspectral illumination. The walls then appeared to be illuminated with colored lights somewhat less saturated than the walls themselves. Thus a compromise situation was set up, for a part of the perceived color was attributed to the illumination and a part to the walls.

On a different occasion, Cramer projected lantern picture slides on a yellow screen. Houses that would have been seen as white on a white screen retained their original whiteness; that is, the yellow of the house in the scene was attributed to yellow illumination. When the slide was thrown out of focus, the white house lost its object color (its whiteness) and also its three-dimensional appearance. With extreme malfocusing, the scene became simply a cluster of various hues and no object color remained. In another case, a blue square appeared as gray when projected onto the yellow screen. This is how it should have appeared, for complementary parts of the spectrum were being mixed. A blue dress of a child, however, was perceived as "blue in yellow illumination."

The physical basis of color constancy

Each case of reflected radiation—that is, each target surface—possesses a so-called object color. This is its property of modifying the radiation falling on it by means of absorbing some wavelengths and reflecting others. It is a virtually fixed characteristic and plays some role in determining color constancy, although in Cramer's illustrations the role is not great.

If a target is viewed sequentially under two different illuminations, or if two identical targets are viewed concurrently under two different illuminations, producing two consequent surface-color perceptions, they tend to be similar but not actually identical. This is another way of stating the compromise described in Cramer's first example. The similarity of the perceptions is favored by the identicalness of the target surfaces, while the dissimilarity of the perceptions is favored by the differences in the two illuminations.

Another way of illustrating the influence of the reflectance of the target is to compare the effect of doubling it and the intensity of illumination. When illumination is doubled, little difference is made; when reflectance is doubled, a great difference is made in the color of the surface viewed. In both cases the total radiation leaving the target surface for the eye is the same. Consequently, one cannot expect to alter surface color greatly by spectral changes in illumination unless they are extreme in comparison with the spectral sensitivity of the target surface. This principle pertains naturally to a faulty appreciation of the illumination level of a scene. Photographers must be aware of this or else they will underexpose a stage scene containing great contrasts and overexpose a flat outdoor scene.

Physiological color mechanisms

Visual adaptation enters into the determination of color and color constancy. By far the majority of situations met with from day to day provide for the visual mechanism to adapt to variations in illumination in the direction of maintaining color constancy. That is, adaptation works in the direction of minimizing both lightness variations and chromatic variations and thereby promotes color constancy. The most common example is that a target that looks white in daylight does not look yellow under ordinary incandescent illumination once the observer is adapted for that illumination. Exposure to the incandescent radiation induces adaptation more to the yellow than to blue because the radiation is blue-deficient. Hence there is greater blue sensitivity of the retina and a "white" target looks white.

Although it is not established that the process of color contrast is a retinal affair, it is generally taken to be that of a very fundamental physiological process (one probably more basic than color constancy). Hence, in

the cases in which color constancy and color contrast are similar, constancy is attributed to the contrast process.

For example, a target that appears reddish will be achromatic when illuminated by "green" (the radiation that is the complement of the reflectance of the target), if there is no background associated with it. Let a background that is spectrally nonselective (that is, "gray") now be used, illuminated by the same "green"; the target will resume its original reddish color. This is a case of simultaneous color contrast. The retinal induction from the illumination is effective in restoring the original color, which was absent when there was no target surround to reflect the "green" to the eye. This same general effect is supposed to operate to some degree in many other situations where the target reflectance and the illumination are not merely complementary or reciprocal to each other. On the other hand, the same principles in certain cases work in the very opposite direction.

Factors at the perceptual level

The two sets of factors for producing color constancy that have just been mentioned do not wholly account for color constancy. Authorities include what they call "interpretive" factors or "psychological" factors. These are difficult to come to grips with and descriptions are rather unsatisfactory. Much more needs to be done to make the laws governing higher neural processes tangible and respectable. The most that can be said at present is that color constancy, as influenced by these higher processes, is enhanced by all the factors that can be used to enhance the object character of the portion of the field looked at. Visual resolution of the spatial microstructure of a target tends to result in its being seen as a surface rather than as film, volume, or aperture, and the likely accompaniment of this is color constancy.

The investigations that have enabled the most comprehensive outlook on color phenomena, and thus on color constancy, are Helson's (1964). His work argues for a simple underlying mechanism that accounts for the many diverse phenomena of color vision under all conditions. He has been able to conclude that theories of color perception are based on restricted or distorted conditions of investigation when they attribute more or less independence to reflectance and illuminance; disjoin color constancy, color contrast, and adaptation; and attribute different behavior of these mechanisms to surface and film modes of color perception.

Among Helson's conclusions are the following. Targets above the reflectance to which the observer is adapted take the hue of the illuminant. Targets below this adaptation take the hue complementary to the illuminant hue. Targets close to the adaptive reflectance appear either colorless (achromatic) or greatly reduced in saturation. Targets appearing least saturated are near the adaptation reflectance, and this adaptation shifts

with reflectance of surrounds. The mere alteration in surrounds changed nearly all the hues he used. The hues that are constant—that will shift toward the illuminant or to the complementary hue—depend on their relation to the reflectance of the surround.

The "adaptation reflectance," or the achromatic point, is established in accordance with the viewing conditions at the time rather than with daylight illumination, a factor not acting at the time. Helson also asserts that effects often attributed to the "pressure of other objects in the field" or to unspecified organizational factors can likely be attributed to alteration in "adaptation reflectances" brought about by variation in target and surround reflectances.

The question of what actually remains constant under special illumination has received two quite extreme answers. One is that all nonselectively reflective targets remain colorless in nonspectral illumination, and the other is that constancy is zero for targets with selective reflectance in spectral illumination. Some investigations have supported these generalizations but only because they dealt with restricted conditions. Different setups or more pervasive surveys have produced exceptions. Helson states that nonselective targets near the achromatic point remain colorless in nonspectral illumination whereas others do not. Selective targets whose color in daylight is close to the illuminant color, or complementary to it, tend to retain their hue if they are of low reflectance. In some cases nonselectively reflective targets may look colored and some selectively reflective ones may look uncolored in spectral illumination. By an appropriate shift of surround, a target can be shifted from colorless to its complementary color or to the color of the illuminant.

Among the many virtues of Helson's investigations is the fact that he made his manipulations with neutral targets, targets not seen as familiar objects whose "natural" colors lie within a limited range. All the higher-level personal factors were eliminated or reduced to an insignificant minimum. Hence, we can take his several generalizations as representing the basic processes in operation. All other phenomena that appear to be contradictions to these generalizations are only cases in which some higher-order process is so strong as to transcend what would be provided when only the basic factors are in operation.

Adaptation level

No doubt a much better understanding of the constancy phenomena would be achieved were we to give some consideration to what Helson (1964) has called the *adaptation level*. Helson has pointed out that various authors recognize the universality of such terms as attitude, frame of reference, standard, norm, and anchor in the attempt to explain behavior. At the same time he has stressed the total lack of any quantitative formula-

tion that expresses the general idea in these terms so frequently used. This lack instigated his attempt to arrive at some general quantitative expression usable in experimentation. The result was his formulation of the concept of *adaptation level*. Adaptation level can be defined operationally in terms of the stimulus eliciting an indifferent or neutral response. Adaptation level can be quantitatively determined, since it is this neutral point that defines the frame of reference within which behavior takes place. Helson arrived at the following equation:

$$P = K\frac{(Xi - A)}{(Xi + A)}$$

P is just-noticeable difference, a concept described earlier in this book (page 93). Xi is "judgment" of a stimulus or, shall we say, the perception evoked by a stimulus. Naturally, both P and Xi are to be dealt with in numerical terms. A is the adaptation level itself and the point on which the whole frame of reference hinges. The constant K contains the Weber fraction (relation of just-noticeable difference to the value of the standard stimulus) appropriate for the modality in which the response is being made.

In the equation, if $Xi = A$, then $P = 0$. That is to say, when the response is to a stimulus having the value of the adaptation level itself, then P is zero: there is no just-noticeable difference.

It must be further understood that responses of the reacting individual are not given in quantitative units representing just-noticeable differences. Any numerical scale may be used, as one pleases.

Helson has shown that any numerical scale may be used when two conditions are met and adhered to. The first of these is that K must be the maximum value in the numerical scale used and that, if a P value other than zero is to represent the response when the stimulus is at the adaptation level, it must be $K/2$. The second condition is that if the subjects give their responses in *qualitative* forms that are to be converted into a numerical scale, the responses must preserve linearity between the qualitative and quantitative scales. Helson has shown that the value of K that establishes the numerical scale can be selected arbitrarily and that all K's yield the same value of A so long as the two conditions described are met.

Not all readers can be expected to feel satisfied that they can apply the equation, but it is not necessary to do so yet. It is important merely to recognize that a workable quantitative formulation has been produced. Those who pursue an understanding of human behavior will want to become better acquainted with the concept and its relevance not only to perceptual behavior but to behavior that is studied from other aspects.

SUMMARY

In the present chapter, the problem of objects retaining their identity under varying contextual conditions has been dealt with. The modality

used to illustrate the matter was vision. The objects that an observer sees retain their identity in spite of the fact that the stimulus conditions vary, creating a basic problem for those who attempt to account for sensory outcome on the basis of stimulation. In vision, four major characteristics were dealt with: lightness, size, shape, and color.

It was pointed out that some of the matters usually dealt with as examples of constancy can be dealt with in other ways. One is by dealing with them in terms of the principle of equivalence: One attempts to discover all the various types of stimulus input that produce the same sensory end result. Following this procedure would result in a somewhat different grouping of phenomena, including cases that have not been customarily included in dealing with perceptual constancy.

Yet a third mode of dealing with somewhat the same problems as now subsumed under perceptual constancy is to employ the concept of invariance, which has to do with matters of *lawfulness* of relation. It is not as rigid a notion as constancy and it, too, includes phenomena that have customarily not been dealt with under the heading of constancy.

A fourth relevant concept is Helson's *adaptation level.*

SEVEN

Space Perception

MONOCULAR VISION

One of the most basic features of human experience for the sighted individual is the awareness of an extended domain called space outside himself in which he and other objects exist. To point this out seems unnecessary, and to ask questions about the nature of this domain may seem entirely uncalled for. But space is the name for two separate things, the *experience* just mentioned and what is *supposed* to exist regardless of and independent of the experiencer. The existence of anything outside one's experience is only taken for granted and is thus believed in from indirect evidence and in fact may be described in various ways. Because this is so, philosophers and other scholars have faced various questions regarding space.

Man has developed formalized means for dealing with space as a concept known as geometries, the most familiar of which is Euclidean geometry because it seems to handle consistently the various everyday operations man performs. But other geometries that conflict with Euclidean geometry are needed to describe various special operations and results. As experiencing organisms we feel that Euclidean geometry is correct and that other schemes that formalize space properties differently are simply intellectual playthings. But in fact other geometries have had to be called upon to describe certain physical phenomena and even certain features of visual performance.

As psychologists, we have both meanings of space to deal with. Many of our tasks have to do with relating space as experienced to space as conceptualized in one geometry or another. Geometrized space is taken as external reality and is used as a standard of reference.

Assuming, then, that we exist within an external domain, we may define space perception in two ways, since there are two ways the organism may perform with reference to it. The organism may appreciate only very small segments of the external domain at any one instant and may never integrate these appreciations into an overall guiding framework within which to operate. Or the organism may operate from such a framework provided by some sense modality. For instance, the visual sense enables the organism to receive information from almost a hemisphere of externality at all instants.

The first form of perception (or performance) is a sequential one; the second provides some kind of an appreciation of the total at all instants. The first may be illustrated by the blind man's gathering of information in bit-by-bit exploration with his fingertips, the second by the sighted person's mere glance.

Are we going to call both forms of performance space perception? If we do, we must make some verbal distinction between them. We might call the visual performance *true space perception* because it is an instantaneous appreciation of the domain as a domain. The other performance is not this overall appreciation. There seems to be no way to integrate the original bits of information so as to experience at a subsequent time a total instantaneous experience of a space domain. Tactual experience is at best a sequential matter. So is kinesthetic experience, although it is to be admitted that some kind of correct or effective motor performance can unfold bit by bit, as in a finger maze in which the person can make a correct run though never having before seen the maze. Even in this case, there is no instantaneous conscious appreciation of the overall maze as in the case of the person who has seen it.

While we have just made hardly even a preface to the study of space perception, we have laid the necessary basis for study of the performance of sensory-deprived individuals such as the blind person. Psychology has been busy studying primarily the behavior of the sighted, and thus much of what preoccupies the psychology student in studying space perception is just that. A more complete understanding of space perception will eventually come from the data and concepts derived from comparisons between normal and sensory-deprived persons. Consequently, some attention will be given here to what contributions to space perception can and cannot be expected of the several sense modalities, vision, hearing, touch, and kinesthesis. The body mechanisms involved differ greatly from one another and, therefore, not quite the same contributions can be expected from each.

Vision as a space sense

The first thing to note regarding vision is the fact that information from almost a hemisphere of the space domain is given to the visual sense

organ at any one instant. Photic radiation is focused through a nodal point and the various degrees of intensity of input received from items in space are thus imaged on the retina as a pattern. This pattern, though not a strict copy of the "pattern of externality," possesses lawful ordinal relations to it. Furthermore, the activity propagated through the optic nerve to the brain is preserved in some lawful way and reflected in the neural input distribution to the visual projection area of the cortex. Thus it can be said that what occur at all the various points in this projection area are some sort of coded representations of external space patterns. Not only is space represented but a huge segment of total space, a segment so big that it constitutes a working framework in and of itself. While this framework is made fully functional by means of the motor apparatus of the eyes and the skeletal system, it can be said that space is made meaningful (functional) in terms of vision and what can be imagined (conceptualized) visually. Space experientially is primarily visual space.

Visual space at low levels of illumination

Included in the investigation of visual space is the determination of what the observer sees when illumination is very low and the field in front of the eyes is wholly uniform. Among others, Metzger (1929) investigated this in a room whose wall viewed by the observers was painted a uniform flat white on which no spots, texture, or irregularities were visible at ordinary levels of illumination. This type of homogeneous field is known as a *Ganzfeld.*

Metzger's experimental procedure consisted in using at the beginning a very low level of illumination, at which all observers reported a diffuse "light fog" that filled all the space in front of them. The visual field was thus not a specific or clear-cut surface localized at some distance from them. When the illumination was raised somewhat, the visual field gave the impression of a concave surface oriented at right angles to the observer's line of sight. The whiteness was seen as a film color localized at about the actual distance of the wall. Thus, no microstructure (or texture) was as yet observable. Finally, as illumination was raised still higher, the experience of a surface color was produced; thus it could be said that the observers now saw the wall.

At the lower levels of illumination, the visual target (the wall in this case) fails to control accommodation of the eye. It is only when illumination is raised to the point of producing the experience of a surface that accommodation is likely to occur.

Learning versus immediacy in vision

One way of testing the role of learning in visual perception has been to examine surgical patients who are for the first time made able to form

ordinary images on their retinas. Congenital cataracts and other anomalies had previously deprived the subjects of the ability to form retinal images and thus of the ability to see. Most of the patients were many years old before corrective surgery was performed.

Senden (1932) published some results of testing post-operative vision in such individuals. Recently Révész (1950) carefully examined Senden's examples, eliminating the more doubtful cases. He concluded with reservations that differences in object size could be correctly discerned while recognition of what the objects were could not, even though the objects were familiar to the patients by touch. This applied to people seen as well as objects seen. He found that no clear general statement could be made regarding the visual ability to perceive movement. Furthermore, it seemed that the subjects could not distinguish between two-dimensional and three-dimensional objects. For example, a paper disk and a ball of the same size were indistinguishable.

Touch and kinesthesis as space senses

External items can be apprehended by contact as well as by the photic radiation coming from them: this is the sense of touch and pressure. External items may be put into ever differing and new relations to the individual by reason of his own motions in space and through practice this activity becomes functionally related to the visual input and response. It must be recognized, however, that both contact and motion provide information *sequentially* (bit by bit) and not as an overall pattern, as in vision through photic input. One imagines contact sequentially. Thus, reliving an occasion in tactual or kinesthetic memory is a bit-by-bit affair rather than one having the total appear in an instant. However, as has already been pointed out, kinesthesis may provide for some useful but limited form of unfolding behavior such as tracing a finger maze.

Let us illustrate this by noticing what could be expected of first a sighted person and then a congenitally blind person when asked to imagine a flight of steps. The sighted person can visualize the whole flight all in one instant; it is a total working pattern to him. The congenitally blind would at best be expected to respond only by imagining walking up or down the flight of steps. For him it would be a sequential affair, not an instantaneous accomplishment in which the "representation" would be a timeless total pattern. It would seem then that we could say that space as an overall domain is not a reality to the congenitally blind man in the same way as it is to the sighted person. It is probably not a spatial reality at all. It is possibly only a temporal reality. (Further details pertaining to expectation and experimental information regarding tactual, auditory, and kinesthetic relations to space will be presented in the chapters dealing with these modalities.)

The point, or air, theory

The classical and conventional way of accounting for human visual space perception is to begin with a point and proceed as if all space were made up of an aggregate of such points. This is in line with the old analytical sensation outlook of perception of space as two-dimensional space and made possible by the operation of simple optics because the retina is, in effect, a two-dimensional surface upon which two-dimensional space is represented or copied. The third dimension in space gave the conventional theory trouble. The third dimension was not conceived as representable on the retina, since the retina is only a two-dimensional manifold.

To accomplish three-dimensional representation, two kinds of factor called "cues" were resorted to. One included the peripheral factors: the convergence of the two eyes and ocular accommodation. Since the amount of convergence is lawfully related to target distance, it was thought that convergence could become a learned cue for distance. Accommodation, or focusing of the eyes, was also expected to be a cue for distance, since accommodation is a muscular effect that varies lawfully as the distance of the target is manipulated.

The second kind of cue was the monocular cue. About seven were usually listed. We shall not discuss them at length, for we have pointed them out previously as examples of using one aspect of perception to explain other, concurrent aspects. For example, interposition and elevation are two commonly given monocular cues. (Figs. 7.1 and 7.2.) To describe interposition is to describe what the observer sees rather than merely to tell the metric features of the stimulus. If one object is *seen* interposed

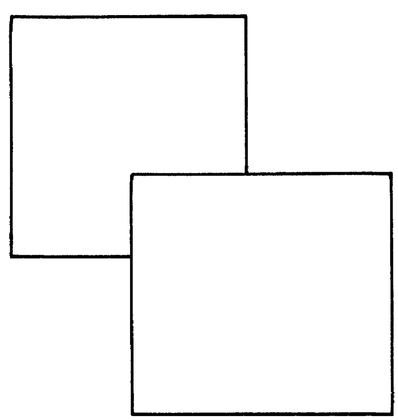


Fig. 7.1. Interposition. If an item partially covers another item, the second will be seen as farther away than the first one.

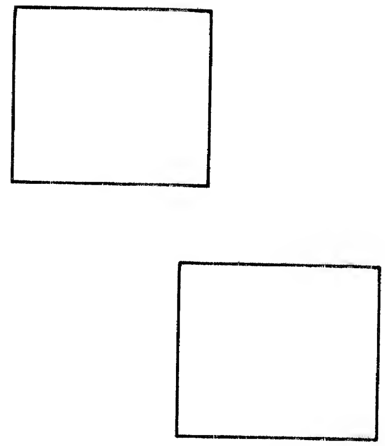


Fig. 7.2. Items higher in the visual field are seen as farther away than items below them.

between the observer and another object, then the object partially covered is seen as farther away. By resorting to these cues, the observer's apprecia-tion of the visual field was supposed to be built up, as it were, bit by bit. This way of dealing with the relations between stimulus and response provides no initial description of overall field structure whereby to account for the roles played by restricted portions of the visual input.

A number of the so-called cues (or conditions) for seeing the third dimension and for localizing and locating objects are binocular. (They will be dealt with in a later section of the chapter.) However, three-dimensional seeing does not depend upon the combined use of two eyes as it can be accomplished with one eye. The use of two eyes can even dis-tort it. When it is of the appropriate sort, the use of two eyes can make three-dimensional seeing more precise for short distances.

The texture-gradient concept

Although the texture-gradient concept of the essential nature of the organism's visually perceived surrounds is implied to some extent in what artists and draftsmen have been doing for centuries, it is a recent develop-ment. It is embodied in a book by J. J. Gibson (1950) that describes the nature of the visual world. The concept is an answer to the puzzle experi-enced by persons who have asked how it is that the organism can perceive the third dimension. Whereas it is known that two dimensions define a plane and can be represented on another plane (such as the receiving sur-face of the retina), how the third dimension can be represented is an age-old question. It was supposed that seeing three-dimensional space requires a mechanism with three dimensions. The question was posed seriously

again and again despite the fact that artists and draftsmen had been representing three-dimensional objects and space relations on two-dimensional surfaces for several centuries.

The first major realization to be made regarding the texture-gradient concept is that the concept implies that all surfaces function as components of a macrotexture of the visual field as a whole. Many surfaces are themselves physically differentiated in some way and are thus seen as textured. In one way or another the whole visual field is textured. The texture possesses various effective characteristics in keeping with the orientation of the surface with reference to the viewer. The surface that lies in the frontal plane provides a virtually undistorted retinal image—that is, there is practically a one-to-one relation between it and the image.

All other surfaces, all surfaces lying outside the frontal plane, form tapered textures in the retinal image. The viewer looks at such surfaces obliquely and, as is well known, the farther end of such a surface is geometrically more oblique to the viewer than its near end. For example, as one looks down at the floor near one's feet, the floor lies almost in the frontal plane. As one views the floor farther and farther away from one's feet, obliquity increases. If one looks out along a hallway, the elements of the floor pattern become smaller and smaller. There are, of course, two reasons for the marked tapering of the texture of the retinal image: increasing distance and increasing obliquity of viewing it. The difference between viewing in the frontal plane and viewing an oblique surface is pictured in Fig. 7.3. In the figure the two surfaces are marked off in equal spaces by lines running from the surface to the eye. The projected image of the oblique plane (the floor surface) is a tapered texture in the retinal image. Figure 7.4 shows the same sort of situation but as viewed by the perceiver. The one texture is seen as the wall, and the tapered texture is seen as the floor extending from near the viewer to the wall.

The term "perspective" applies to the figure but refers not only to perception but to the techniques the artist and draftsman use to produce the kind of perception we are dealing with here. In fact, the term perspective generally refers to four items: (1) the target (the three-dimensional visual field), (2) the two-dimensional representation of a three-dimensional visual situation, (3) the retinal image, and (4) the perception. In common practice perspective is most used for items 1, 2, and 4. It would be helpful if we made some restriction on our usage of the word, so let us use it only for 4, the perception. Let us use "third dimension" to describe the target (1) and "foreshortening" to describe the arrangement of a three-dimensional object in a two-dimensional representation (2) and the form and composition of the retinal image (3). Thus we see perspective and can produce it by presenting a three-dimensional target or a foreshortened two-dimensional representation of the original target. Both of these presentations produce essentially the same sort of retinal image.

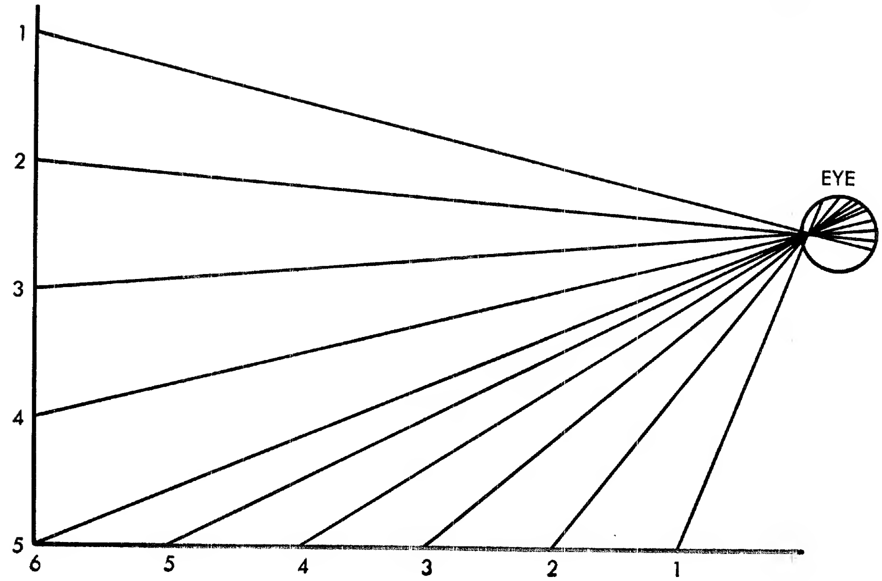


Fig. 7.3. Relation between orientation of surfaces to the eye and the texture they present to it. Frontal plane surfaces present a uniform texture when the target field is uniform. The same surfaces oriented obliquely present a graded texture.

The second major realization involved in the texture-gradient concept is that the visual world of the outdoors is divided by a horizontal line called the horizon. The texture gradients—or the taper of the ground (the field below the horizon) and the sky (the field above the horizon—run in opposite directions. Far-away positions of the field, both in sky and on land, are of fine texture and the two gradients of texture meet at the horizon.

According to the texture-gradient concept, the elements of vision, the origins in considering visual behavior, are not *points* as in the air theory but *edges, corners,* and so on, that is, the abruptions formed by the junctions of various gradients. Visual objects differ in complex ways by reason of differences in gradients.

In all that we have just said we have been describing a definite and lawful relation between features of the three-dimensional domain called space and the representation of it in geometrical terms on the retina. This description is a sufficient answer to the question of how it is that the organism can appreciate the three-dimensional visual world.

There are still other features besides texture-gradient to reckon with. One is that the organism lives in a world in which photic radiation is not perfectly diffuse but instead is directional. Even though at times we say that the radiation from the sun is quite diffuse, we must recognize that it

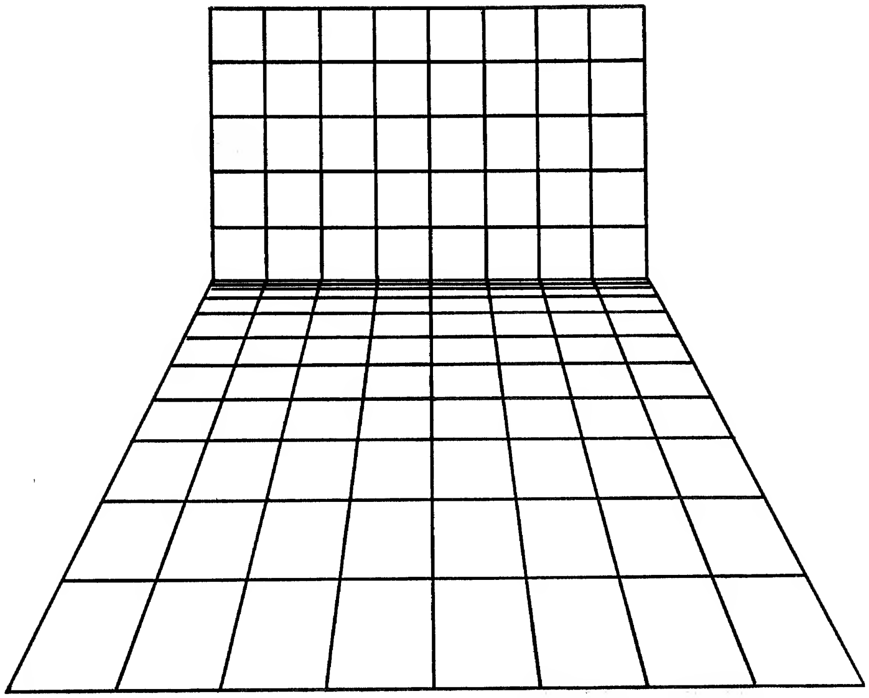


Fig. 7.4. The appearance of the surfaces dealt with in Fig. 7.3

is directional enough to cast shadows. The sun seems to rise in one direction from us and progress above us across the sky until it sets in the opposite direction; thus photic radiation is, in general, downward rather than upward. Shadows are cast on the earth, on the horizontal plane, and not upward toward the sky. The results of the directionality of radiation become an inherent part of the visual-gradient characteristics. For example, depressions in vertical walls are shaded above and lighted below, a perfectly lawful result that is altered only when for some reason illumination comes from below instead of above. But this seldom occurs and then by man-made arrangements. Figure 7.5 illustrates this principle: look at the figure right side up and then upside down.

Equivalence in stimulus situations

Another basic principle in describing visual space perception is the fact that a number of different situations may produce visually equivalent results. Many examples of this are generally subsumed under the heading of perceptual constancy, but there are others that are not traditionally so classified.

The "law of the visual angle" provides for the equivalent viewing of

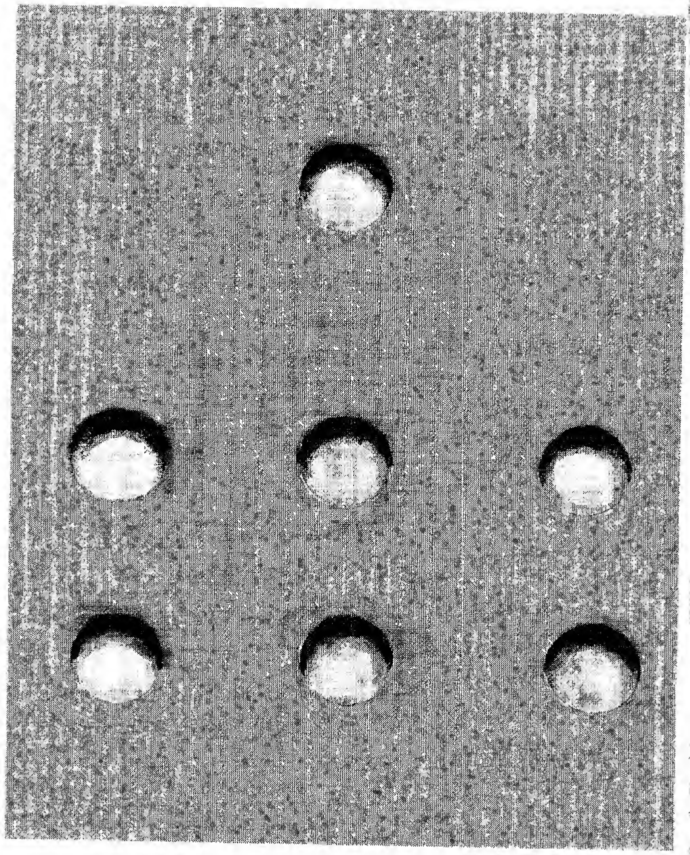


Fig. 7.5. Relation between direction of illumination and consequent shadows to the perception of bulges and recesses. Looked at one way the diagram contains recesses; looked at upside down it contains bulges such as are made by rivet heads.

(or seeing as the same target) an unlimited number of targets differing metrically among themselves and in their orientations and locations relative to the viewer. All the plane targets A, B, C, D, E, in Fig. 7.6 and an endless number of others of various sizes and at various distances from the eye will subtend the same visual angle. Unless there is some difference of structure (texture) within the targets or the surrounding visual field, they will be seen as the same object when presented one at a time.

One of the Dartmouth Eye Institute demonstrations showing that what appears to be may not actually be an interposition also demonstrates a case of equivalence. The lower lefthand part of Fig. 7.7 (a modified version of the demonstration) shows three playing cards set up in a row along the line of sight. They can be adjusted sideways and vertically so that all three

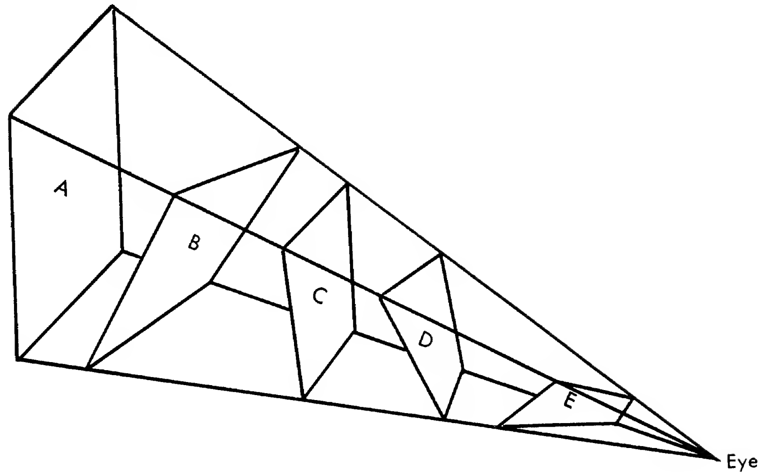


Fig. 7.6. An unlimited number of targets may subtend the same visual angles at the eye. The targets here are A, B, C, D, and E.

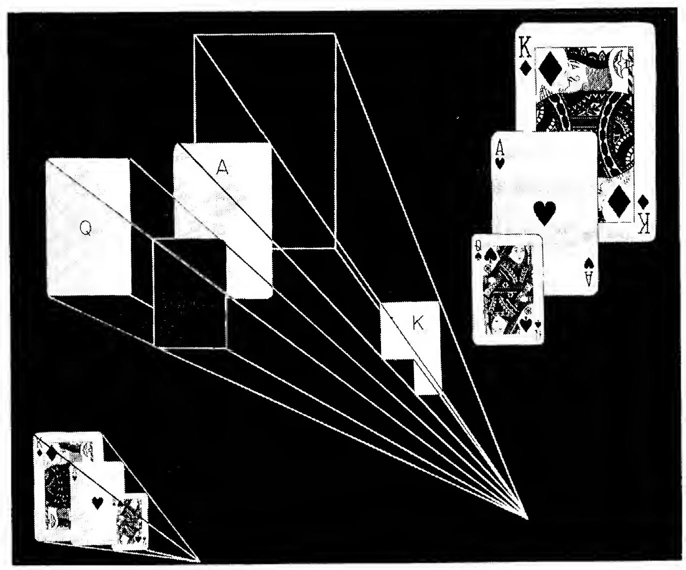


Fig. 7.7. Modified Darmouth Eye Institute demonstration showing interposition and equivalence.

can be seen, one of them fully and the others partially. This is a case of interposition (as dealt with earlier in the chapter): In the upper right part of the figure, the queen of spades is nearest the eye and is seen as nearest; next is the ace of hearts and then comes the king of diamonds. Here we have chosen sizes so that the cards all would subtend equal visual

angles in the actual situation represented. If these cards were placed directly in line, the queen of spades would just cover the ace of hearts, and the king of diamonds. This is shown in the lower left part of the figure.

Our problem is to show that the same (equivalent) visual effect can be produced when there is no interposition, that is, when no part of one card is "covered" by any part of another. The first step is to reposition the cards with respect to the eye. In so doing their relative sizes must be changed so that they, as before, will subtend the same visual angle. The king is now represented as closest to the eye and thus must be the smallest card. The ace is kept in the mid-distance, and the queen is now farthest away. Of course, as before, they are not directly in line, else only the king could be seen. The king card is now altered by having its lower left section cut away. Thus when looked at from the represented eye position the ace will now appear to cover the very portion of the king that has been cut away. This is true, of course, only if the two cards are positioned so that the notch in the king card is in line with the upper right portion of the ace card. Using the same principle, the lower left part of the ace card is cut away so as to be in line with the upper right portion of the queen card. Looked at from the represented position (where the visual angle lines converge) the situation will appear to be the same as the original one despite the new positioning and changed sizes of two of the cards. Thus here is a good example of equivalence.

The distorted rooms of Ames demonstrate the role of visual angles in the production of equivalences and differences. Ames (1946) showed that an endless series of rooms of various shapes will look like a given rectangular room (a "normal" room) just so long as certain conditions in their construction are satisfied. First examine Fig. 7.8. You will notice that the room looks rectilinear and in every way normal, but there seems to be something the matter with the sizes of the faces of the two persons looking through the windows. The person to the left is smaller than the person to the right. This difference would be expected only if one were truly smaller than the other, for the windows of the room appear to be of equal size. The two persons seem also to be equally far away. It is very puzzling why the two persons differ in size, for human faces do not generally, if ever, differ as much in size as these do. Let us now turn to the construction of the room.

In Fig. 7.9, B is a normal room with two side windows and two back windows. E is the position of the single eye viewing the room. Dotted lines from the eye show the visual angles subtended by the windows and the corners of the room; the lines may be considered also as *lines of direction*. A is the distorted room. The same lines of direction as in B are used for the features of this room. Since the walls in A are in a different position than those in the normal room, the windows have to be of different sizes so as to subtend the same visual angles and lie in the same directions as they do in the normal room. It will be noted that the back windows are larger than

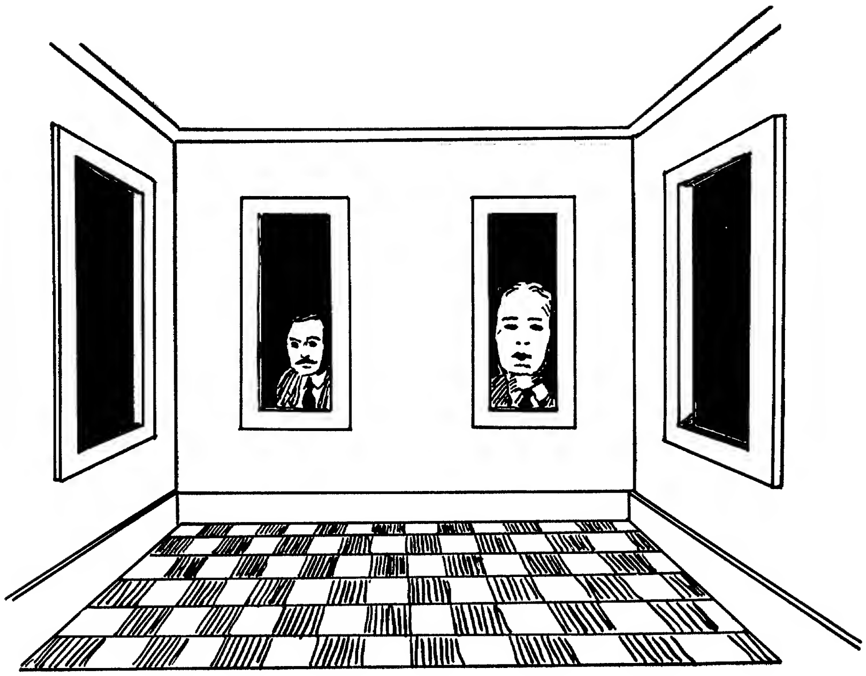


Fig. 7.8. A distorted room with two persons looking in windows. (Drawing from photograph in M. Lawrence. *Studies in human behavior*. Princeton, N. J.: Princeton University Press, 1949, Fig. 10.)

they are in the normal room and that the left window is larger than the right one. The two circles are meant to represent the heads of the people in Fig. 7.8. Hence, if one person looks in at the right window and the other at the left window, the two heads will be of very different apparent sizes, since the windows are of the same apparent size and the two faces subtend different visual angles. This difference in angular subtense is brought about by a difference in the distances of the two faces from the viewing position. Figures 7.8 and 7.9 demonstrate only one of the types of distorted rooms built by Ames.

We have been discussing only lateral distortions—those necessary to make the room appear normal when viewed from a point to the right of center of the near wall—but vertical distortions can also be presented for comparison with the lateral ones. People of equal height standing upright in the room, one against the rear wall on the left and the other against the rear wall on the right, do not look equal in height. In fact, even when the room is photographed the two people do not appear to be equal in height. This is of course due to the fact that the person to the left is farther away from the viewer than the partner to the right. The use of distorted rooms

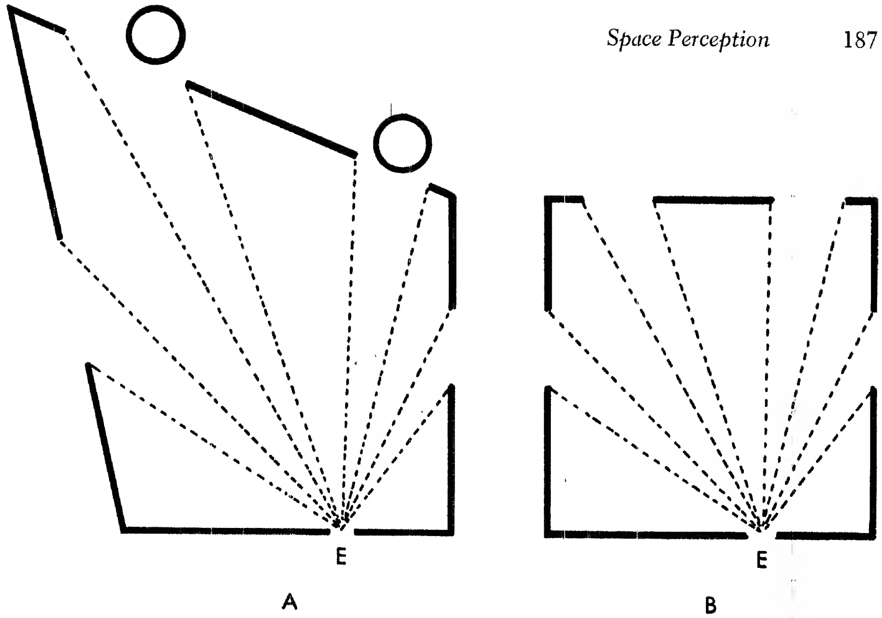


Fig. 7.9. Floor plans of a normal rectilinear room (B) and a distorted room (A), the windows in both subtending the same visual angles at the eye (E). The circles represent similar-sized objects that may look unequal in size in this context.

for monocular viewing demonstrates exceedingly well the operation of the law of the visual angle.

The basis for the whole set of effects in the distorted-room example is the preclusion of operation of factors other than the law of visual angle. Common situations include other factors, and so when they are eliminated very startling results are achieved. Adopting a single fixed viewpoint allows for presentation of a control situation in which planes or surfaces are viewed at several discernible orientations from the point of viewing. What is seen at first is a room with a back wall in the frontal plane. Moving the target planes does not change the overall appearance, because the visual angles that provided for the perception of a normal rectilinear room in the first viewing are maintained in the new target called the distorted room. All that is necessary to make something look smaller than it would be expected to look, judged from the first viewing, is to place the object farther away from the perceiver; this is most readily done by simply moving one end of the wall of the room farther away (as in A of Fig. 7.9). Thus, when an object of fixed size is placed against a feature of the new wall (itself enlarged), that same object looks smaller than it did before. It becomes small for two reasons: (1) it subtends a smaller visual angle than it would when closer to the viewer and (2) it is smaller relative to a fixed feature of the viewed scene than would be a second, metrically equivalent object (as a second face). To put the matter briefly, the visual field was so structured as

to *preclude* size constancy for the *test* targets used (the movable, enlargeable walls) and to *promote* size constancy for objects introduced, by following the law of the visual angle.

Rooms properly distorted for binocular viewing have also been made. Since the two eyes view a room from different positions, room form has to be quite different than for one-eyed viewing. It is not necessary to describe such rooms here, except to say that their walls have to be complexly curved. Such rooms were precalculated in the Ames laboratory and were built by boatbuilders, who were accustomed to fabricating curved surfaces.

BINOCULAR VISION

In the discussion of space perception so far, we have dealt with factors that operate in seeing with only one eye. The coordinated use of two eyes introduces additional factors in seeing a third dimension and thus allows a means of seeing, within short distances, three-dimensional characteristics not possible with only one eye. Once the distance exceeds a certain limited range, the two eyes cannot provide space perception any better than one eye. Why this is will become apparent.

The initial fact in binocular vision is that the two eyes are separated from each other and, as a consequence, receive inputs from a target from two different vantage points. This results in the formation of somewhat different images on the two eyes when they are fixated on a given target. The nearer the target is, the more unlike these images are. Once the target distance exceeds a certain limit, the two images are, in effect, totally alike, and the perceptual effects that result from two-eyed seeing vanish.

Another way of putting the matter is this. When pointing toward near objects, the two eyes *converge*. The greater the convergence is, the more dissimilar are the images of the two eyes. With convergence, the images are asymmetrical, and so the study of the effects of asymmetry in retinal images has been of prime importance in what is known as physiological optics, the study of optics as exemplified in the visual system and the visual consequences that result.

The organism learns on the basis of the orderly relation between retinal images and the properties of the space domain. This learning is the development of experiences of size, location, distance, and the like and the ability to react in lawful ways to externality. Hence any condition that, artificial (as with lenses) or not, produces the image differences also produces the appropriate experience of some three-dimensional scene. All that remains for the experimenter is to learn what external three-dimensional situations produce what retinal images in the two eyes. Once this is known, the experimenter can produce substitute situations and use them as laboratory presentations. In accordance, then, with the laws pertaining to such matters, he can produce predictable experiences whether common or bizarre.

Diagrams to show binocular effects

Throughout the remainder of this chapter, diagrams will be used to show the directions of photic rays from target to retina as a means of accounting for many characteristics in binocular vision. In such diagrams, two circles represent the two eyes. Lines drawn from points or lines external to the two circles cross within the circles and extend to the sides of the circles opposite to their entrance (that is, to the retinas). Such arrangements represent focusing and image formation. The images are represented by the spaces between the lines as they reach the opposite sides of the circles. One pair of such lines originating at a common point represent the optical axes of the eyes, which is to say that the optical axes of the two eyes point toward the single locus at which the two lines originate. On the two retinas, points that lie to one side of the fovea refer to a given side of the target field, and points to the opposite side of the fovea refer to the other half of the target field. By such diagrams many relationships between target elements and retinal components can be depicted.

Binocular effects arise from the fact that the two eyes, being separately located in space, do not form the same retinal images of any target: the two images may differ in size, shape, and location. All such differences are lawful optical consequences and depend upon the position of the eyes in relation to the various components of the visual field at a given instant. Movements of the head or the target of that instant call for oculomotor adjustments to point the two eyes toward an appropriate location on the target or in the field in general. Part of this adjustment is the variation in the amount of convergence of the two eyes and the pattern of asymmetrical convergence when a target is not directly viewed or fixated.

Diagrams can be drawn to show the various relations between the target and the eyes. The target is generally indicated by a line such as *ab* in Fig. 7.10. The fixation point *p;* is the line from *p* to each eye reaches the retina at the fovea and approximately represents the optical axis of the eye; the lines from *p* to *f* show the direction in which each eye is pointing. Lines from *a* and *b* (the bounds of the target) show where the bounds of the retinal images lie. The distance on a retina between the two lines indicates the size of the retinal image, and the distances of these lines from the foveal line *f* show whether the image is symmetrical or asymmetrical. Usually the images are asymmetrical, and the amounts and directions of asymmetry and the differences in the asymmetries of the two retinal images are among the lawful features of information that the visual system utilizes to produce three-dimensional seeing.

Diagram A in Fig. 7.10 indicates the conditions under which the two eyes are symmetrically convergent on a distant target. The retinal images are small and internally are nearly symmetrical—that is, the portion of the circle falling immediately to the left of *fp* is nearly equal to the portion

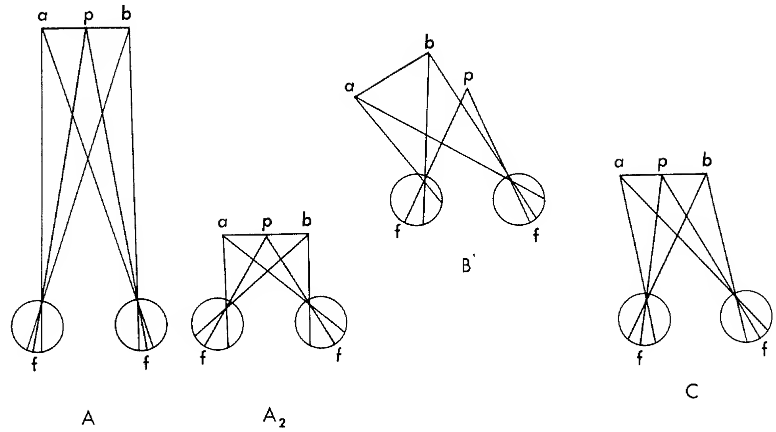


Fig. 7.10. The characteristics of retinal images in binocular vision under several conditions.

falling to the right. In Diagram A_2 the target is much nearer, and thus the eyes are more greatly converged. The images are larger, and asymmetry is far greater. That is, the portions to left and right of *f* are relatively much different from what they were in A. Thus, we can say that target distance determines the size of the retinal images and also their internal composition (symmetry-asymmetry). In diagram B, the target location and orientation to the eyes is asymmetrical, producing some additional characteristics in the retinal images. First of all, the sizes of the two images are unequal; second, the patterns of internal asymmetry of the two eyes are unlike. In diagram C, the target is fixated but, nevertheless, the two eyes are not symmetrically related in space to it. This provides for a lesser amount of asymmetry within the two images and for a lesser difference between the two images. Beyond these elemental situations a number of others can be described but it will not be necessary to do so here.

Retinal disparity

The points on the two retinas that function to give "single vision" for a given target point are called corresponding points. For example, the points on the two retinas that represent the fixation point are corresponding points. While there are many corresponding points on the two retinas for any given fixed posture of the two eyes when they are fixated on a given target point, there are many points on the two retinas that are noncorresponding.

Images from target points that do not fall on corresponding points on the two retinas are said to be *disparate,* and in monocular vision they would result in two different experiences involving two different perceptual di-

rections. Disparities can be of two sorts, vertical and horizontal. It is the horizontal disparities that underlie the stereoscopic perception of third dimension.

Disparities can also be spoken of as crossed and uncrossed, as shown in Figs. 7.11 and 7.12. Figure 7.1*a* shows the separate left and right images of an outdoor scene with the horizon and a roadway leading to it. The vanishing point is labeled *v* for each *image.* In Fig. 7.11*b* the two images are fused, which means that both eyes are fixating upon the vanishing point of

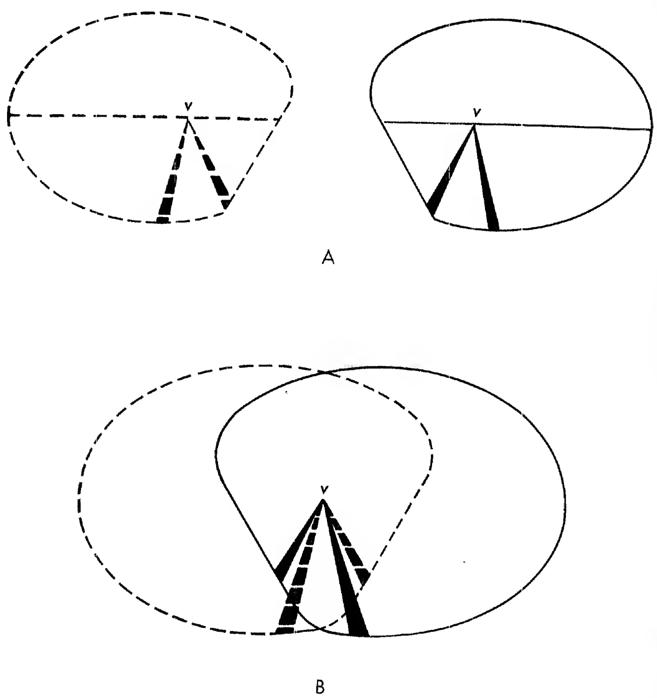


Fig. 7.11. Crossed disparity. (J. J. Gibson. *The Senses Considered as Perceptual Systems.* New York: Houghton Mifflin, 1966, Fig. 9.14.) (See text for explanation.)

the road. The two *v*'s fall on corresponding points on the two retinas, in this case, the two foveas. It will be noted, however, that certain portions of the rest of the two images do not coincide. Failure to coincide represents disparity. The kind shown in this case is crossed disparity. At the level at which the fixation point is imaged (the vanishing point), disparity is absent, but above and below this disparity begins and progressively increases. In this gradient, the left eye's image is displaced to the right, and the right eye's image is displaced to the left. This is why the disparity is called crossed disparity.

For fixation on a point nearer than the horizon, the portions of the

two images at the level of the fixation point will be made to coincide, but there will be disparity above and below this level, as in the previous example. For distances nearer than the fixation point, the disparity is crossed (Fig. 7.12).

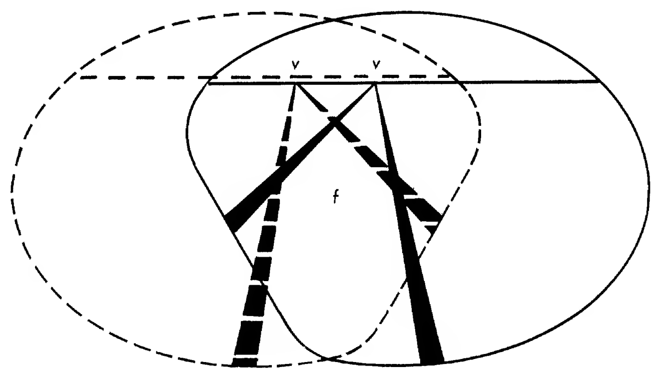


Fig. 7.12. Uncrossed and crossed disparity. Uncrossed disparity is produced by target elements beyond *f*, the image of the fixation point. (J. J. Gibson. *The senses considered as perceptual systems.* Boston: Houghton Mifflin, 1966, Fig. 9.14.)

It is apparent from these diagrams that all disparity does not lead to "seeing double" (or diplopia). In both examples, the two eyes are converged on some point and a part of the visual field is thus being represented on corresponding portions of the two retinas. The target involved in the fixation is the target that the individual is attending to. Retinal disparities progress from the level of fixation upward and downward. Disparity is the basis for perceiving various distances. On the other hand, when *no* portions of the two retinal images are made to coincide for the targets viewed, there is no basis for disparity gradients, no basis for seeing singularly what is being looked at, and double vision occurs.

The topic of double versus single vision is so complex that it cannot be covered here. No single rule can be given to the beginner in understandable terms that would enable him to make discrete predictions regarding double vision and merely vision of third dimension. A very common demonstration of double vision can be produced by holding up one's index fingers at eye level. One is placed about 5 or 6 inches from the eye and the other at 12 to 15 inches. Looking at the near finger, one sees two far fingers, one on either side of the near one but of course at a greater distance from the eye. Looking at the far finger, one sees the near finger doubled. This sort of result is much different from that of extending one's arm outward and then looking at any given point out along it: in no case is any part of the arm seen as double though not all parts are equidistant. In some re-

spects (certain geometrical respects) the two situations are alike, but in certain others they must be different. They both involve items at different distances, but in one case the items are discrete (the fingers). In the other case, they are parts of a continuum (the arm).

Asymmetry in retinal images

Inasmuch as the two eyes converge when they point toward near targets and do not converge when quite distant targets are viewed, students of vision have at times supposed that the kinesthesis that would be involved in positioning the eyes would be a "cue" for the perception of depth, or third dimension. Workers have not been overly successful in providing tangible evidence that convergence, with its consequent kinesthetic innervation, provides a basis for discriminating third dimension and distances.

There is, however, another factor that is brought into play where convergence is varied. Convergence varies the amount of asymmetry of the retinal images. In diagram A of Fig. 7.13, the two eyes are fixated on a near

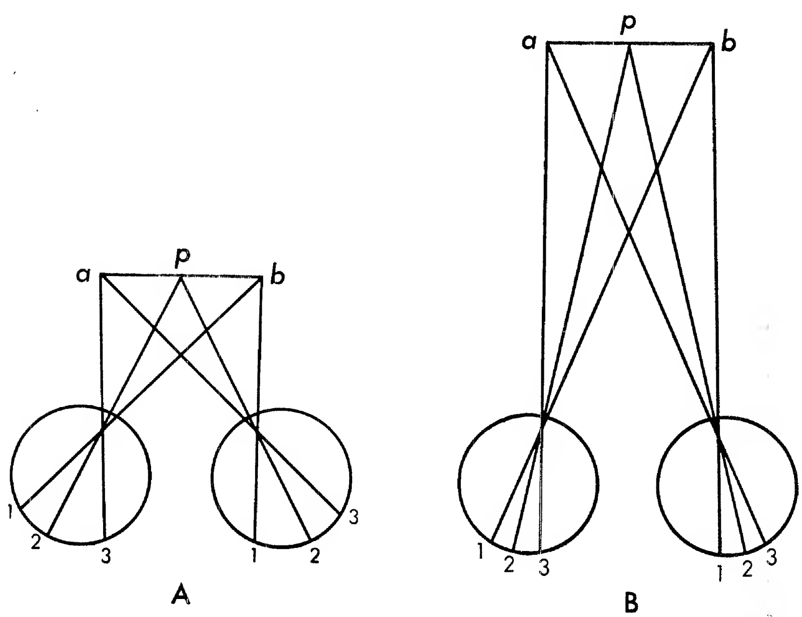


Fig. 7.13. Convergence varies the amount of asymmetry in the retinal images. The target is *apb*; 1–2–3 is the image. In A 1–2 is unequal to 2–3; in B the two are almost equal.

target and the images of the two eyes, though alike, are internally asymmetrical. Although the eyes are pointing toward the center of the line *ab*, the images of *ap* on the left eye, for example, are larger than the images of

pb on the same eye. Likewise, the image of *pb* is larger for the right eye than is the image for *ap*. Were the eyes pointed toward a very distant target, this inequality (asymmetry) would be reduced to the vanishing point, as suggested in diagram B. Thus, in keeping with target distance, the images may vary from having considerable asymmetry to having no asymmetry at all.

The fact of decreasing asymmetry for targets farther and farther away can be utilized in producing distance effects, as in museum displays, for example. In such displays, there are generally two portions—the midground and the foreground occupied by animals and other objects and a background painted on the wall behind. The background is often flat (not curved), and considerable asymmetry in the visual images of the two eyes is thus already brought about (Fig. 7.14). Although what is painted in the background is meant to depict something far away, it does not do so to the fullest extent. The asymmetry brought about by a flat background can be to some degree eliminated by curving it (Fig. 7.14*b*). The two portions of

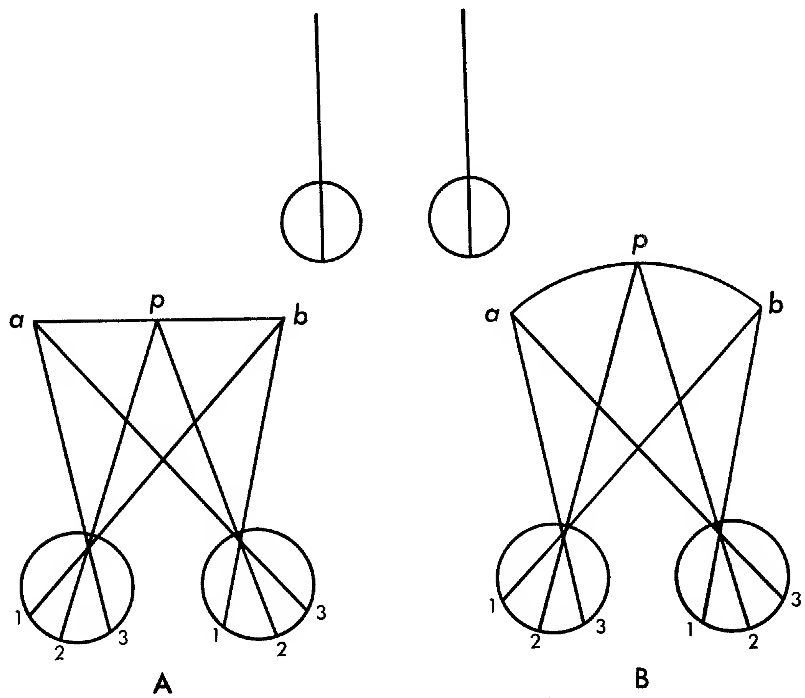


Fig. 7.14. Curved (concave) targets tend to produce symmetrical retinal images, even when the targets are near, and thus simulate distant targets. The target is *apb*; 1–2–3 is the image. The retinal images in B are much more nearly symmetrical than those in A.

the retinal images in Fig. 7.14*b* are much more nearly equal—if not totally so—than in 7.14*a*. As a consequence, the background produces the kinds of retinal images brought about by viewing distant scenes.

Tilt in the third dimension

Another example to show the relation of ocular activity, externality, and visual perception is the viewing a luminous line in a dark room. The question put to the perceiver is whether the line is vertical or tilts in the third dimension. Actually, when out of the vertical the line may or may not be seen as tilted. The retinal images produced by a vertical-line target (Fig. 7.15) are parallel to each other and are vertical. Since the two eyes

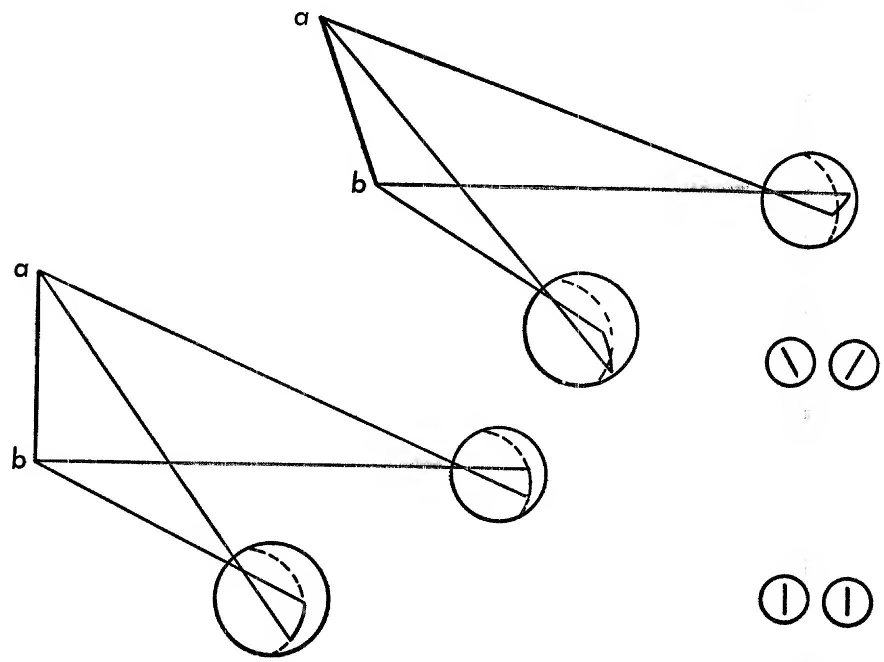


Fig. 7.15. Positions of retinal images for *ab*, a vertical-line target and a tipped-line target. When the line is vertical, the images are vertical; when the line is tipped away from the eye, the images are rotated laterally outward at the top.

are separated horizontally, the "views" obtained by them converge—that is, they are slightly like side views rather than views from straight ahead.

If the line target is tipped, the affect on the retinal images is different from what it would be if there were only one eye involved viewing the line from straight in front. With monocular viewing all that would happen to

the retinal image would be a foreshortening. If the line were tipped nearly to the horizontal position, the line would become very short, approaching a mere point.

With the slightly sidelike views of the two eyes converging toward the line, however, the retinal images would undergo not only some foreshortening but also some rotation. Rotation of the two images is in opposite directions from the vertical and is a form of retinal disparity, the stimulus basis for seeing the line as tilted.

If the line target is a luminous one in a dark field, so that there is nothing extraneous to influence the viewer, the line may continue to look vertical even when the target is tilted. Ogle and Ellerbrock (1946) studied the perceptual effects produced by the target situation just described and found that the observer did not always see the line tilted when the target was tilted, at least not unless it was greatly tilted. They came to the conclusion that the eyes rotated in their orbits to compensate for the rotations of the retinal images. The proper rotations of the eyes prevented the images from falling on points different from those when the line target was vertical, and, therefore, the target was still seen as vertical. The eyeball rotations just described are called cyclofusional, or cyclotorsional, movements. That the kinesthesis from cyclotorsional movements did not, in itself, become interpreted in some fashion as indicating a change in target position is an example of how insensitive the organism is to actual eye position. This is an argument against the organism's supposed use of convergence as a "cue" for distance.

To preclude the use of binocular vision (that is, the production and utilization of different images in the two eyes), one may place the luminous line target at a considerable distance from the eyes; the two eyes do not then converge but take up parallel pointing positions with reference to the target.

Stereoscopy

Stereoscopy has to do with the principles underlying the production of third dimension in binocular vision. Some visual fields seem three-dimensional for reasons other than those we are about to describe. On the other hand, the dissimilarity between the images in the two eyes and the differences in location of the images in the two eyes play decisive roles in the perception of the third dimension.

Figure 7.16 indicates where various points in space are projected onto the retinas of the two eyes when the eyes are in a given position. When the two eyes are fixated on a common point, the images of points nearer to or farther away than the fixation point are located as indicated in the figure. The fixation point is at A, and it is projected on the fovea of each

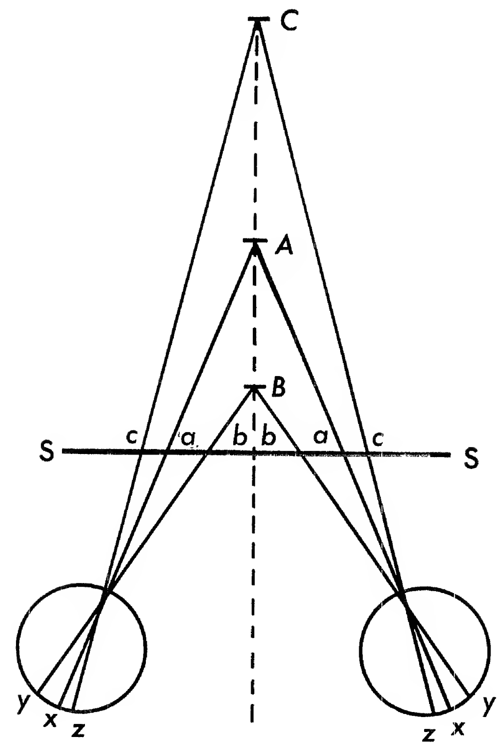


Fig. 7.16. How points at various distances are projected onto the retina at various distances from the fovea. Point A is at the fixation point. *B* is nearer and *C* is farther away. If one substitutes a stereogram, SS, points *A*, *B*, and *C* would be represented by points *a*, *b*, and *c* on it. Points *a*, *b*, and *c* are projected onto the retina as points *x*, *y*, and *z*.

eye. The point beyond the fixation point is C and it is projected onto the nasal portion of each eye. B, the point nearer than the fixation point, is projected onto the temporal portion of each eye.

The line SS represents a plane that cuts through lines from points A, B, and C. Actually, the line represents the frontal plane. On this line, near points such as B are represented by points (*b*) inward from (medial to) the points (*a*). Likewise, points such as C more remote than A are represented medial to the point A on the plane. These points on the frontal plane then constitute a *plane projection* of the three-dimensional situation A, B, and C.

With this knowledge in mind, we can construct pictures to be viewed through a stereoscope so as to have them be perceived in the way we wish. A stereoscope is an optical instrument through which a separate target for

each eye is viewed. The redirection of the radiation from the targets is such that they are seen as a single target with an enhanced third dimension. Before we diagram the optical principle used in the stereoscope, let us examine a couple of stereograms, as shown in Fig. 7.17.

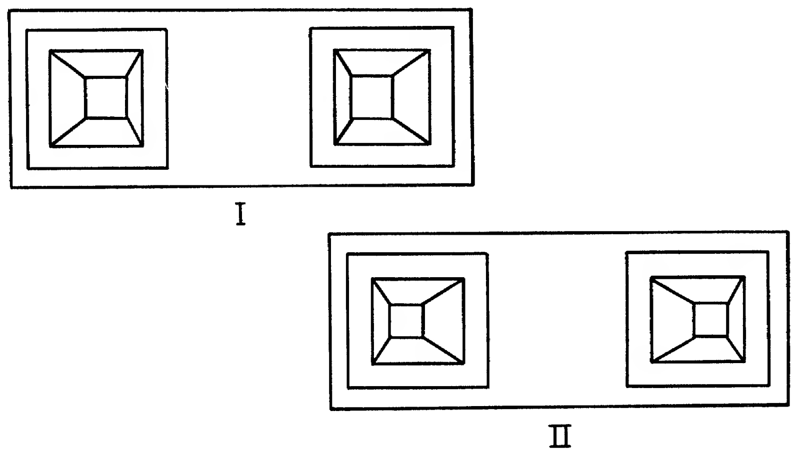


Fig. 7.17. Two stereograms. The components in the targets of the top one are so shifted that they will be seen as a truncated pyramid. In the bottom stereogram, the shift is in the opposite direction and the targets will be seen as a hallway.

In stereogram I, the two pictures, or targets, are so constructed that they will be seen as a truncated pyramid with its small portion (or apex) toward the viewer. This is because the small squares are shifted toward the center of the target. (The view is indicated by point *B* in Fig. 7.16). In stereogram II, the opposite is true and the picture is one of a long hallway through which one looks to the doorway at its far end (point *C* in Fig. 7.16).

Figure 7.18 indicates the optical principles of the stereoscope. It will be seen that radiation is redirected by the prism lenses *P* so as to simulate origins different from the actual ones.

At this point, a rule of thumb is helpful. Parts of the visual field look to be where they would be if the photic flux came straight from them to the eye. This rule is pertinent, for we shall be using lenses, prisms, mirrors, and the like in subsequent examples to change the direction of the flux from what it was as it left the target. This rule is a recognition of the fact that it does not make any difference how many times the flux is redirected between its leaving the target and reaching the eye; it is only its direction as it enters the eye that counts. In diagraming the flux and its redirection (or refraction), the rule is used by projecting outward from each eye to

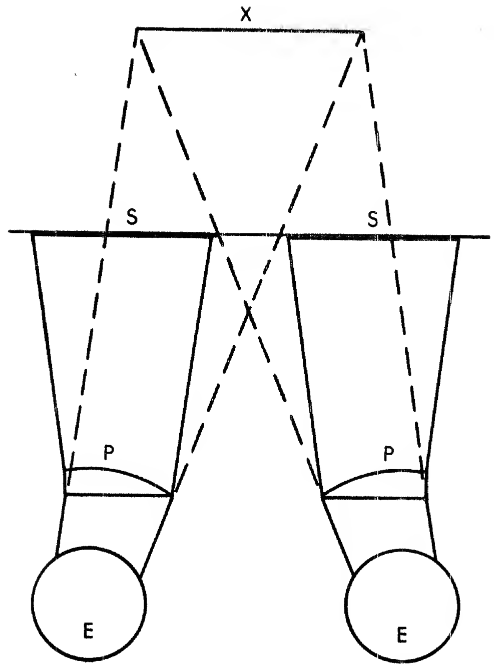


Fig. 7.18. The Brewster stereoscope. EE are the eyes of the viewer. PP are the prisms that redirect the radiation from SS, the stereogram items, so as to enter the eyes as if coming from target X. Because the radiation is coming from such a direction and is common for both eyes, a single picture is seen.

indicate the direction of flux origin and then determine where the directions for each eye intersect. The intersection is the point from which the radiation seems to originate. When this rule is applied, one chooses the borders of a target for use in diagramming. In that way one can illustrate the size and position of the phenomenal object.

In examining the diagram of the stereoscope, it will be seen that the flux is as if it were originating from one target (X) instead of the two actual ones (SS). The perceived object thus displays enhanced third dimension. This is accomplished by the fact that the two slightly dissimilar targets are projected onto the retina in a manner similar to the projection of a three-dimensional target viewed from considerable distance.

While the consideration of the visual qualities of objects other than shape, size, and location is not strictly a topic for this chapter, we might mention one such item, an effect brought about in conjunction with the enhancement of apparent third dimension by stereoscopic means. The objects that stand out from each other at the various distinctly different

distances change their surface qualities and mechanical character. Targets that are seen as people with bodies of flesh and blood tend to turn into stone-hard objects. What is pliable becomes rigid. This would seem to be some indication of the intimate relation of the widespread effects brought about solely by the manipulations of the forms of the retinal images of the two eyes.

Additional optical instruments

Binocular disparity may be manipulated by three instruments, the stereoscope or telestereoscope, the iconoscope, and the mirror pseudoscope. Attention to how these manipulations are produced will further aid the understanding space perception and such attention should increase assurance regarding the assertion that the structure of visual space (what is seen

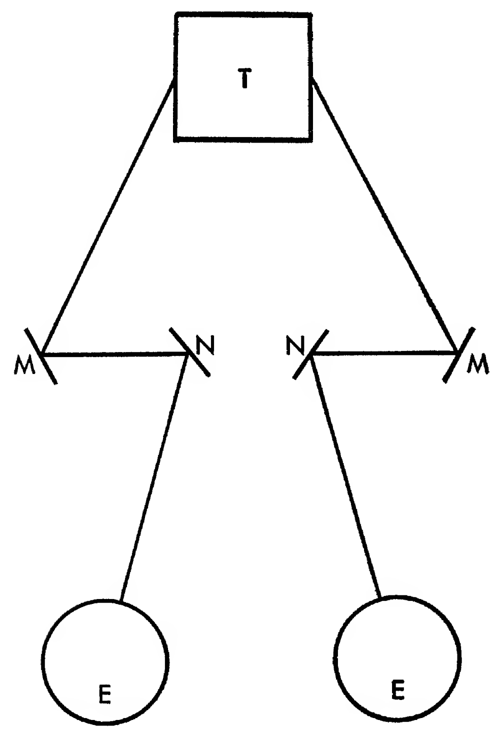


Fig. 7.19. The telestereoscope. This is essentially Wheatstone's stereoscope modified for viewing a single target. The distances between mirrors M and M can be made quite great, so that the two "views" of target T can be diverse, enhancing the disparity and therefore the appreciation of third dimension. The system in effect increases the distance between the two eyes, EE.

external to oneself) is precisely controlled by the nature of the retinal images of the two eyes in relation to each other.

The stereoscope described earlier was of the kind invented by Brewster (1856) many years ago. Wheatstone invented a different sort, based on the telestereoscope, in which mirrors instead of prisms are involved. In the telestereoscope, (Fig. 7.19) the target, T, is viewed by reflection from two sets of mirrors. The first set, M and M, receive reflection from the target from two widely separate positions. These "views" will be quite different owing to the fact that they will be more like side views. The reflections of the target are picked up by mirrors N and N, which are close enough together to be used by the eyes in a somewhat converged position. Thus the eyes with their normal separation and in a quite usual posture of convergence will receive radiation from a target as if they were widely separated. The amount of retinal disparity is, of course, enhanced. This enhancement functions to increase the depth of the target, that is, its third dimension. When the telestereoscope is used to view distance targets, the separation of mirrors M and M may be as much as several feet. In this way, the precision of third-dimensional location is greatly enhanced. This principle has been used for range finders in connection with the sighting of guns.

The difference between a telestereoscope and Wheatstone's stereoscope is that, whereas the telestereoscope has a single target reflected to mirrors M and M, in the stereoscope, mirrors M and M are replaced by separate stereograms. That is, at one mirror there is instead a picture and at the other mirror there is another picture, a slightly different view of the same target, or scene, as in Brewster's stereoscope. Also, between items M and M the distance is greatly reduced from what it is in the telestereoscope.

The iconoscope (Fig. 7.20) produces effects opposite to those of the telestereoscope. The iconoscope minimizes binocular disparity and thus reduces the appreciation of the third dimension. Two sets of mirrors (or prisms) M and M are placed as close together as possible and the radiation they pick up from the target is directed to mirrors N and N separated by the usual amount to redirect it to the slightly converged eyes.

The third instrument, the mirror pseudoscope (Fig. 7.21), is so constructed as to reverse the disparity that would occur with the naked eyes or with the two instruments just described. The left eye is made to receive what the right eye would ordinarily receive, and the right eye is made to receive what the left eye would receive. This reversal of disparity makes far targets look near and near targets look far. It will be recalled (from page 191) that targets farther away than the fixation distance produce uncrossed disparity and targets nearer produce crossed disparity. From this, it can be understood that crossing and uncrossing disparity has a third-dimensional effect in visual perception.

With a pseudoscope a convex target can be made to look concave, and

a concavity can be made to look like a bulge, which is, of course, a case of making that which is near look far and that which is far look near.

Vision with size lenses

One means of manipulating the shapes of retinal images, and thus the perception of objects and spatial relations, is by the use of *size lenses.*

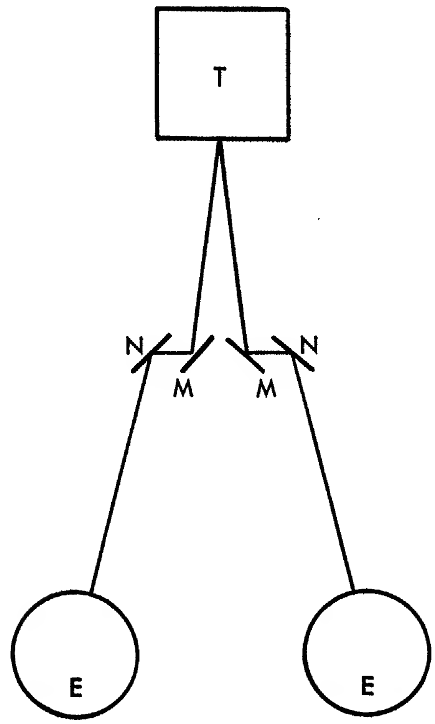


Fig. 7.20. The iconoscope produces effects just oposite to those of the telestereoscope. The effective separation of the two eyes is minimized, and thus disparity in the two retinal images of the same object is reduced.

All the lenses commonly used in everyday affairs are *power lenses.* They focus radiation and form images and consequently they are limited for certain experimental purposes dealing with space perception. Used in certain ways, they produce the perception of blur, often contrary to what is needed. Power lenses are of several shapes: biconvex, planoconvex, biconcave, planoconcave, and so on. In every case, the two faces of the lens are not parallel or concentric (Fig. 7.22).

On the other hand, a lens whose surfaces are parallel or concentric is

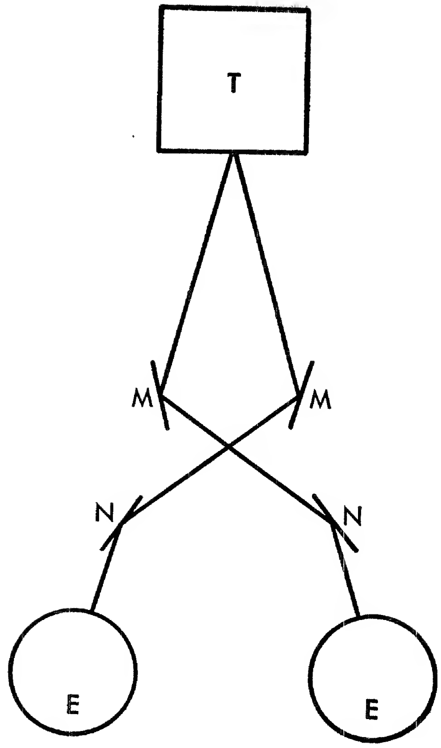


Fig. 7.21. The mirror pseudoscope interchanges the "views" obtained by the two eyes and thus reverses the disparities of their retinal images.

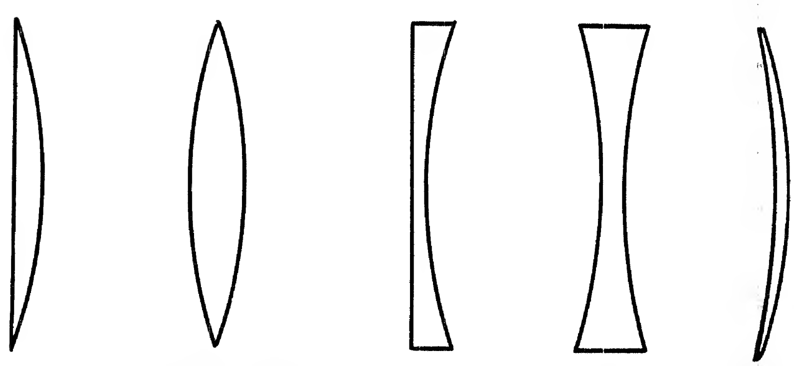


Fig. 7.22. Various common forms of power lenses.

called a size lens. The simplest is in the form of a plane piece of glass curved about a single axis (Fig. 7.23). Since the lens has a single axis of curvature, it is designated by the meridan that is used as the axis and is

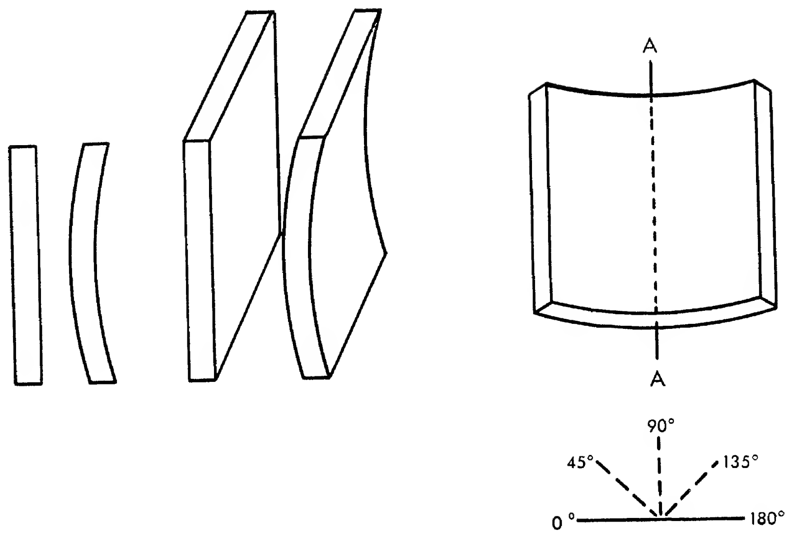


Fig. 7.23. The meridional size lens is essentially a curved section of originally plano glass. It does not focus radiation as a power lens does. Its axis is AA and the axis position is designated in degrees from zero to 180.

called a meridional size lens. Meridians are designated in degrees from 0 to 180, beginning with 0° at the left horizontal (9 o'clock on the face of a clock). The vertical meridian is 90° and the horizontal meridian (at 3 o'clock) to the right is 180°. All designations fall within this degree range. A lens formed by cupping a piece of plano material is called an overall size lens. Meridional size lenses magnify the retinal image in the direction at right angles to the axis of curvature.

If a meridional size lens is worn in front of one eye, the image in that eye is magnified in one direction and thus differs from that in the other eye. The combined retinal pattern for the two eyes simulates, to some extent, the pattern of some natural three-dimensional target. The natural target is quite different, of course, from the one actually involved at the time. When an axis-90 size lens is worn in front of one eye, certain unique perceptual end results are produced.

THE LEAF ROOM. One of the best target situations for studying space perception with size lenses is a leaf room, a small room, say a cube of about seven feet, open on one end. It is called a leaf room because, typically, it is covered on the inside (ceiling, walls, and floor) with artificial leaves to break up the familiar linear stimulus features produced by corners and edges.

When an observer stands at the open end of a leaf room (Fig. 7.24) with an axis-90 lens in front of his right eye, the room's appearance is

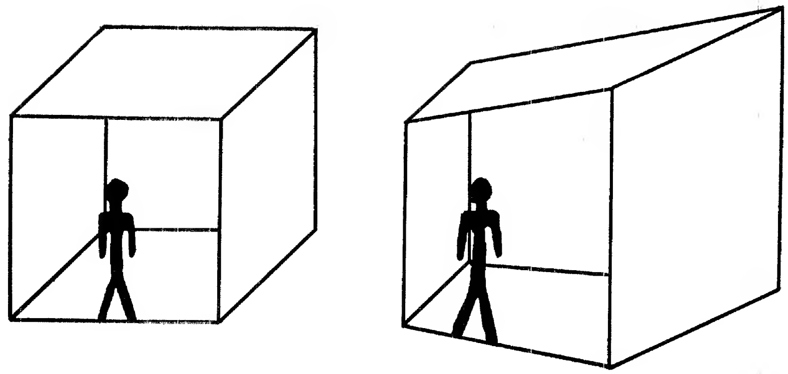


Fig. 7.24. The leafroom as metrically and perceptually seen when an axis-90 size lens is worn in front of an observer's right eye.

greatly changed from normal. It no longer appears rectilinear. The back wall is no longer in the frontal plane and its right side is farther away than the left. Although the observer is standing at the midpoint between the two side walls, they no longer appear to be equidistant from him: the wall on the right is much farther away than the left one. The ceiling slopes upward to the right, and the floor slopes downward to the right. The leaves are larger in the right half of the room than in the left. All these differences are manifestations of a taper toward bigness on the right and littleness on the left.

The description of the leaf room viewed under the influence of a size lens seems interesting but not too significant. However, it is one demonstration of the important ability to manipulate space perception experimentally. The use of size lenses in still other situations indicates the considerable sensory conflict that can be engendered and the personal insecurity that can be evoked. Manipulation of such situations brings out that not only can pure sensory results be obtained but so can other results that could be called emotional and social. Use of the size lens may be actually one potential way of studying personality differences.

The optical features of wearing an axis-90 size lens in front of one eye are depicted in Fig. 7.25, showing how wearing the lens produces the perceptual results in the leaf room. The rule of thumb regarding perceived direction is again employed: the image in one eye is elongated, which participates in changing the perceived directions or locations of the limits of the target. The new directions are such that the left side of the target *a* is brought closer, to *x*, and the right side *b* is moved farther away than normally, to *y*.

OBLIQUE SIZE LENSES. If two size lenses are to be worn, they must be rotated to oblique positions—as shown in Fig. 7.26—if distortion effects are

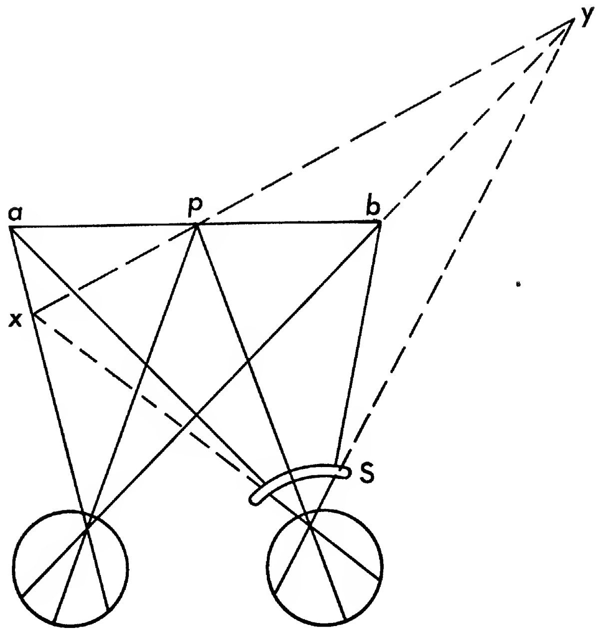


Fig. 7.25. The psychooptical principle of the axis-90 size lens worn on the right eye. Target *apb* is seen as *xpy*, since the lens redirects the light in one meridian so as to enlarge the retinal image in that dimension.

to be produced. The magnifications are then oppositely oblique in the two retinal images, reminiscent of the oblique tilts of the two line images described on page 195. On looking at the floor the perceptual effect of wearing oblique size lenses is to tilt the appearance of the floor either upward or downward. Which it will be depends on whether the axes of the lenses are rotated inward or outward at the top: when the rotation is inward, the tilt is upward; when the rotation is outward, the tilt is downward. The amounts of tilt also depend on the field conditions in general, including the distance of the targets viewed. The farther away the targets are, the less the tilt will be. Instead of tilt, there is a change in apparent size and elevation in relation to the viewer. When size is magnified, motion is increased. When size is diminished, motion is reduced. This effect pertains aptly to water surfaces containing waves. If the observer is in a boat actually affected by waves, he expects the boat to be buffeted about in accordance with the size of the waves. If it turns out that the mechanical and visual effects of the waves do not tally, a perceptual conflict is produced. When the waves are smaller than would tally with the buffeting of the boat, the result is very disturbing, because one never expects little waves to toss boats much. Seeing waves larger than would tally with the boat's buffeting is less dis-

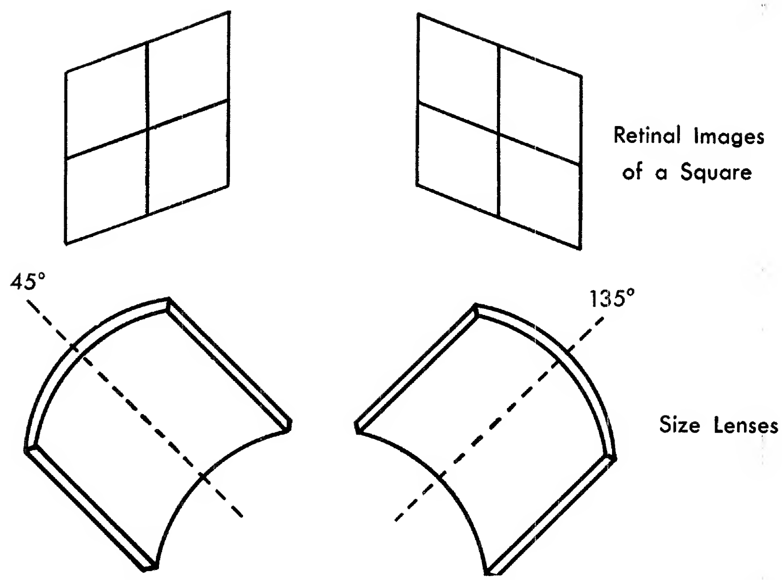


Fig. 7.26. Two size lenses worn obliquely distort the retinal images of a square target. (S. H. Bartley. *Beginning experimental psychology*. New York: McGraw-Hill, 1950, Fig. 32.)

comforting, because an observer may be used to standing on solid land while looking at big waves and not being tossed at all. Hence, the big-wave, little-toss situation is natural, whereas the other is highly novel and sometimes productive of uneasiness and motion sickness.

Effect of instrumental magnification

It is to be recognized that in all the cases in which binocular vision was manipulated, the manipulation was accomplished by varying the characteristics of the retinal images in one way or another. Various optical devices not yet mentioned have been useful in such manipulations. One such device is the field glass, or binocular, which of course increases the size of the retinal images.

When one attempts to manipulate visual input to the eye, one of the first considerations is whether or not, and in what way, the instrumental manipulation of retinal images compares with images produced in natural (unaided eye) situations. The image produced by a given target can be increased in size in three ways: (1) the target may be enlarged; (2) the target may simply be brought nearer the eye; (3) instrumental magnification may be used. While these three operations in general accomplish the same thing, they are not fully identical. The first operation enlarges all

portions of the target and thus the image to the same degree. The second operation does not do this, as will be shown. The third operation, while not involving any shift in metric distance of the target, is otherwise somewhat like the first operation, but the net visual result is different from that of the other two. Operation 1 causes the target to appear as far away as before, but the object seen is larger. Operation 2 results in seeing the object remain the same size but stationed much closer to the eye. Operation 3 results in seeing an object of a different shape than the original; it is foreshortened or flattened.

Figure 7.27 illustrates certain features of change in the three situations. Diagram I shows a three-dimensional target and how the third dimension is represented on the retina. The far edge of the target can be seen if the target consists of a transparent substance or by rotating the target slightly or by viewing it obliquely from above or below. The near (front) edge is a, the far edge b.

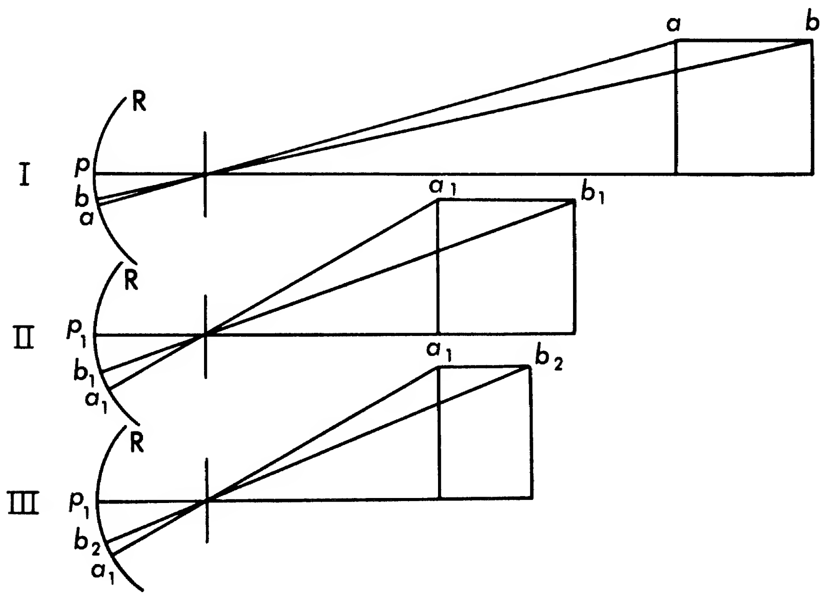


Fig. 7.27. The effect of distance and instrumental magnification on the retinal image. Decreasing target distance increases retinal-image size. So does instrumental magnification. The latter increases all parts of the image proportionally, whereas the former does not.

In diagram II, the same target is brought closer to the eye. If the near edge a_1 is now half as far away from the eye as before, the far edge b_1 is more than half as far away as before. Thus, not all parts of the target are shifted in the same proportion and this will be represented in the amounts

to which various components of the image of the target are changed. Not all components will be changed a similar amount.

In diagram III, the target is constructed as it would have to be were both near and far edges each brought in to one-half their original distance from the eye. This involved collapsing the distances between near and far edges. With binoculars, all features of the target are magnified equally (in effect, brought nearer to the eye in equal amounts) and thus the shape seen is a foreshortened specimen of the object produced by the original conditions.

In complex targets, various changes in proportions of the image produced by instrumental magnification bring about changes in the internal structure of the object seen.

With certain targets the flattening effect is replaced by another sort of distortion called Chinese perspective. In Fig. 7.28 the top and bottom edges

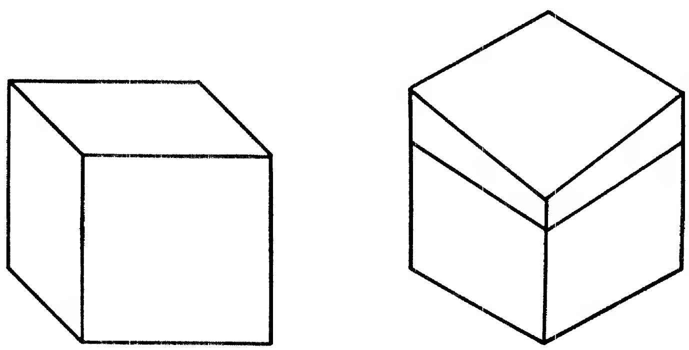


Fig. 7.28. A cube and a solid with Chinese perspective.

of a cubical form no longer look parallel. This effect can also be accounted for by the diagramming procedure.

Oculomotor mechanisms

Oculomotor mechanisms play a considerable role in determining the nature of visual perception, space perception in particular. There are three distinct oculomotor mechanisms: (1) the pupil, which manipulates to some extent the amount of radiation reaching the retina and, optically, the depth of field; (2) the muscles of accommodation that aid in regulating the shape of the lens and, therefore, the focusing of radiation onto the retina; and (3) the extrinsic muscles that regulate the postures of the eyeballs (their convergence) so that the two eyes point to the target being dealt with. These activities are reflexive and the individual may not be aware of their existence and most certainly is not aware of their operation. Nevertheless, they form a part of the organism's expression of relation to the en-

vironment. On the one hand, the character of the impingement plays a major role in determining patterns of activity and, on the other, such patterns are somewhat determined by the cognitive activities in the cerebral cortex. They are, to say the least, part of the overall perceptual response. All three mechanisms are linked together to provide for certain necessary optical features for seeing. The accommodative and convergence mechanisms in particular are linked together so that the conditions that call for a certain amount of accommodation also call for a certain amount of convergence.

ACCOMMODATION. Accommodation is the refractive state of the lens and depends upon its shape. Although the act of seeing is considerably more than the production of an appropriate refractive state forming a maximally "sharp" image on the retina, it does generally include this act. How lacking in "sharpness" an image can be and still be usable by the owner is a question. The emmetropic (or "normal") eye can produce its maximally sharp image when parallel rays enter the eye, and it can likewise focus optimally on the retina when the radiation originates at nearby targets as well. This is to say that the lens in such an eye is highly variable in shape.

The greatest distance from which the radiation from a target can be properly focused on the retina is called the *far point*. In the emmetropic person, this distance is infinity. In the near-sighted, or myopic, person the far point is not infinity but some finite distance, let us say within twenty feet. In all persons there is also a point that marks the nearest a target can be placed and still be clearly seen. This is called the *near point*. In the far-sighted, or hyperopic, person the near point is often scarcely within arm's length, whereas in the normal 10-year-old, the distance is about 7 centimeters. As age increases, the near point recedes. At 25 years of age, it is typically about 12 centimeters; at 40, it is 22 centimeters; at 55, it is 51 centimeters; at 70, it is often 400 centimeters. As the person progresses toward old age, the far point typically moves closer and closer.

The linear distance between near point and far point is called the *range of accommodation*. The difference between the refractive power of the eye (measured in diopters) in a minimally and a maximally accommodated condition is called the *amplitude of accommodation*. The lens is said to be minimally accommodated when it is adjusted to image the most distant target on the retina. The strength of a lens in diopters is the reciprocal of its focal length expressed in meters. Thus a lens of one diopter will focus parallel rays at a distance of one meter. If the lens was to focus them at 0.5 meter, the dioptric power of the lens would be 2.

There are supposedly four sources of accommodation: (1) a tapered pattern of stimulation on the retina, as from a poorly focused image; (2) the convergence of the two eyes, for the greater the convergence the nearer the target and thus the greater the need for accommodation; (3) the tonic, which is the accommodation produced by the normal tonus of the accom-

modative muscles; and (4) the proximal, the added tonus engendered when the target is perceived to be quite near as, for example, within arm's length.

CONVERGENCE. When the person attempts to respond to a visual target, his eyes converge upon it. We say he fixates it, and by this is meant that the optical axes of the two eyes point to some portion of the target. On the other hand, responding to a target may involve exploratory movements of the eyes as well as fixations. Normally, the eyes maintain what are called conjugate positions at all times with reference to the target viewed—that is, they point to some portion of the target, not to some point nearer or farther away. If the target is quite distant, the optical axes of the eyes are parallel. As the target is brought nearer, convergence of the axes occurs and increases as the target is brought still progressively nearer. This activity is supposedly brought about under the supervision of a fusion center in the brain but how this is accomplished is not specifically known.

Convergence is regulated not only by the fusion center but by several other factors. There is supposedly a certain amount of tonic convergence. The relatively passive tone of the several extrinsic eye muscles is such that the eyes are somewhat converged. A third factor is the state of accommodation of the eyes. The fourth factor involved in convergence is the proximity of the target.

Convergence, like accommodation, is measured in diopters, but in this case in *prism diopters*. One diopter is one centimeter deviation of the eye produced at a distance of one meter. For an interpupillary distance of 60 millimeters, the optical axis of each must deviate (converge) 3 centimeters (that is, one-half of the interpupillary distance) in order for fixation of a target to occur regardless of its distance. If the target is one meter away, each eye converges 3 prism diopters.

VIEWS ON OCULOMOTOR BEHAVIOR. The whole science of visual care, whether it involves optometry or ophthalmology, hinges on several concepts regarding the relation of oculomotor activity to the behavior of the person as a whole. The classical viewpoint, represented largely in the concepts developed in the days of Helmholtz, holds that vision is primarily a matter of optics, fixed anatomy, and a number of fairly stable reflexes. Accordingly, the person is what these reflexes collectively make him. They develop as a feature of general neurological maturation and are not to any great extent trainable. The seeing process is primarily an optical one in which the principles of optics, eyeball size and shape, and muscle size and length participate to provide a certain net result. Sometimes the eyeball is so long that the radiation comes to a focus slightly before reaching the retina; sometimes it is so short that radiation does not quite come to a focus upon reaching the retina. In these cases, myopia (near-sightedness) and hyperopia (far-sightedness), respectively, result. Myopia is rarely if ever

present at birth but develops later on, particularly in the early years of schooling.

Newer views with regard to vision are very different from the old. The essential difference lies in the trainability of vision. Some current views recognize that the human being has to learn to see. This learning, we should say, is twofold: a motor learning and a development of comprehension of the environment, the most significant feature of which is its spatial aspect. Motor learning and comprehension must go hand in hand. If learning is involved, we must caution ourselves about the two alternatives: it can be inefficient or anomalous learning or efficient and adequate for the demands put upon the individual. It can go wrong as well as right. Since these two possibilities exist, the logical conclusion arrived at by some is that growing individuals, as a routine thing, may need some training in order that the seeing process may develop as it should. A still further consideration enters the picture—namely that the visual demands made upon most individuals in our time are far greater than those put upon previous generations. This makes training necessary when it might otherwise be bypassed with relative impunity.

Kinesthetic and vestibular factors in space perception

While the perception of space as a three-dimensional domain is primarily a visual one, various other sense modalities are involved along with vision. In the development of space perception, bodily movement is involved in making perception a dynamic or active affair.

One can think of the space domain not only as something that has geometrical dimensions but also as a field of form in which gravity acts in a certain constant direction for those who remain on or near the earth's surface and in which other forces also act, namely those due to acceleration. Hence, the body's sense modalities are brought into play and in certain ways become interrelated with vision. This interrelation can be harmonious or conflictual. Many studies have been made on the interrelation of vision and other senses, showing how they are factors in changing what is experienced visually. To the extent that such studies fulfill this function, their discussion belongs in this chapter. Insofar as they more predominantly pertain to the elucidation of the mechanisms and reactions based on these senses, they belong elsewhere and will be dealt with in other chapters.

SUMMARY

Space perception was dealt with under two headings, monocular vision and binocular vision. Certain features of a three-dimensional domain can be perceived monocularly, while the use of two eyes properly coordinated makes additional contributions to three-dimensional perception.

The first division of the chapter dealt with what could be seen with a single eye. A major feature was the presentation of the texture-gradient theory of space perception and the contrasting of it with the classical or traditional view. The texture-gradient theory was an effective explanation of how third dimension can be perceived despite the fact that the retina is essentially only a two-dimensional receiving surface for optical images.

Another feature of this part of the chapter was the discussion of what constitutes a space sense or modality and a depiction of the features of input to the sense organs of the various modalities and what they have or have not to do with space directly. The subject of distorted rooms was included, a subject that provides for illustrating some of the most fundamental features of space perception.

The second division of the chapter dealt with binocular vision, or the vision provided by orderly relation in the operation of the two eyes. This began by discussing the differences in the images on the two retinas as targets straight ahead and targets off to one side are viewed with the two eyes.

Retinal disparity, stereoscopy, and the characteristics of various instruments that modify optical input to the eyes were dealt with. The topic of size lenses and their various perceptual effects was included.

The rules of accommodation and convergence as both motor mechanisms and means to provide appropriate optical effects were discussed. The final topic was the contribution of nonocular kinesthetic and vestibular factors in the perception of space.

EIGHT

Perception of Figure and Form

Perception of figure and form is space perception. It is dealt with in a chapter apart primarily because it is customary to distinguish between perception of figure and perception of form and the other aspects of space perception. Space perception as a label has most particularly to do with where objects look to be, how far away they seem, and in what direction they are located. It generally includes the matter of perceived size and three-dimensionality. In short, the label generally refers to the sensory responses that have to do with space as an overall manifold or orientational framework. Once these have been considered, one can move to finer and more restricted details. Even then, he is still dealing with space perception. The present chapter as contiguous to Chapter Seven considers some of these details of space perception.

APPROACHES TO THE STUDY OF FIGURE AND FORM

Some of the variety of approaches start with figures and forms and deal with the conditions for their detection and discrimination. Some approaches begin with unstructured fields and progress by introducing a kind of minimal departure from homogeneity (or unstructuredness), building in a logical, systematic, and experimental way to higher degrees of complexity. We shall introduce findings from each of the two approaches.

Target versus stimulus

Earlier we stated that stimulus refers to the energy that evokes a response but many of our stimuli are not as yet fully definable in energistic

terms. That is to say, what is talked about as a stimulus is not at all the energy that impinges on sense organs but is rather something described in sensory terms. This is particularly true in vision, where what is generally called the stimulus is what the experimenter himself sees. Hence, what is called a stimulus is a human response. This response is given in standard or universal terms, thus forming a reference with which to compare the responses of the experimental subject or observer. From the standpoint of natural science, many stimuli and stimulus specifications of perception are yet unknown. We carry on research by the use of a kind of surrogate—the standard or reference just described. Because we need a label for the item that is erroneously (figuratively or idiomatically) called the stimulus, we have chosen the word *target*. The target is thus the surrogate for the true stimulus. In experimentation, the objective is often to compare the observer-response description with the standard description of the target. At other times, when energistic terms are used to define the stimulus, the objective momentarily becomes one of ascertaining sensory outcome as a function of manipulating the energistic variable or group of variables. The distinctions between the two operations are not customarily kept clearly in mind.

It would be helpful if our language could somehow indicate the classes of stimuli and the classes of response quite separately. For example, it would be helpful if we could say that the targets that give rise to objects are figures and the targets that give rise to seeing mere shapes are forms and the targets that give rise to mere differentiation of visually perceived structure are compositions. There would then be no doubt as to what was meant. We may not be ready yet to put into practice a consistent convention for terms, but the need for one is not thereby lessened.

For more specific use of terms, Bartley has suggested that, in designating the bounds of the target and of the seen object and the processes that underlie the seeing, three different words be used. For the target, the bounds would be the *border*. For the seen item, the bounds would be the *edge*. The neural processes underlying the sensory end result would be *contour processes*. This would supplant the more common use of "border" for all three categories and the loose, interchangeable use of border, edge, and contour for each of the categories. The intent is of course to make it easily possible for a reader or listener to know which category is being referred to.

The words already mentioned by no means exhaust the list of words used; some of the others are additional terms for boundary and some are for internal or overall (area) characteristics of what is seen and for describing the targets. For example, "outline" and even "shape" are two for the first purpose, and "structure," "texture," "configuration," "form," and "figure and shape" are used for the latter. It is obvious that some words have reference both to the bounds and to the internal features of what is seen—or to

the stimulus surrogate, the target. It is also obvious that whatever convention is adopted will run into contradiction with present usages.

Outline, edge, and contour

As was initially stated, one approach to the study of figure and form begins with determining the simple conditions involved in figure and form production. Three of the terms we listed above refer to the phenomenology involved during the first step of figure and form production. For example, if drawing a line across a homogeneous field involves certain departures from linearity, the line may be seen as forming the boundary between a figure and the nonfigure portion of the field. Some writers call this line the contour of the figure. Another name for it is the outline. In fact, when figure is segregated from nonfigure by a line, that line had best be called its *outline*. The line can also be said to indicate the edge of the figure. We have already pointed out that synonyms have no place in science, and to the question of whether these three terms—contour, outline, and edge—are actually synonyms the answer would seem to be that they are not. Outline is the boundary of a figure when the boundary is indicated by a line. An edge is the bound of a figure when the issue to be emphasized is the mere extent of the figure as an area. Contour might well be the word to use when the nature of the edge or bound of the figure is emphasized, as in determining whether a figure has tapered contours or abrupt contours.

Specification of target shape

Shape is a target characteristic that is quite difficult to specify once one goes beyond the traditional geometrical forms such as squares, triangles, and pentagons. Attneave and Arnoult (1956) describe nine methods for generating target shapes, some their own, some those of others. Each method is difficult to describe adequately in brief terms. Perhaps the best way to describe the first method is by quoting from the authors.

> When all points have been plotted, a straightedge is used to connect the most peripheral points in such a way as to form a polygon having only convex angles. This operation will usually leave some unconnected points within the polygon [Fig. 8.1*a*]. When a point falls within some small, arbitrarily chosen distance of the proper perimeter [e.g., the point between segments 7 and 8 in Fig. 8.1*a*], it is included even though it makes a slightly concave angle, since otherwise an indentation practically dividing the shape into two parts might later occur. The sides of the polygon are numbered, and the points remaining inside are assigned letters. The table of random numbers is then used to determine which of the central points is connected to which side. In the example given, Point C was connected to Side 2, forming in the process Side 10 [Fig. 8.1*b*]. At this stage in the construction, the possibilities of connecting points have been changed.

Point A may now be taken into Sides 3, 4, 5, 6, 7, 8, or 10, but not into Sides 1, 2, or 9. Point B may be connected only to Side 2 or Side 10. If Point A is connected to Side 5, forming new Side 11, there remains only the possibility of connecting Point B to Side 2 or Side 10 [see Fig. 8.1*b*]. Connecting Point B to Side 10 completes the shape, which finally appears as shown in Fig. 8.1*c*.

It will be noted that every step in the procedure is determined either randomly or by the elimination of all other possibilities. Furthermore, every step is completely determinate and can be duplicated by anyone using the same rules and the same selections from the table of random numbers.

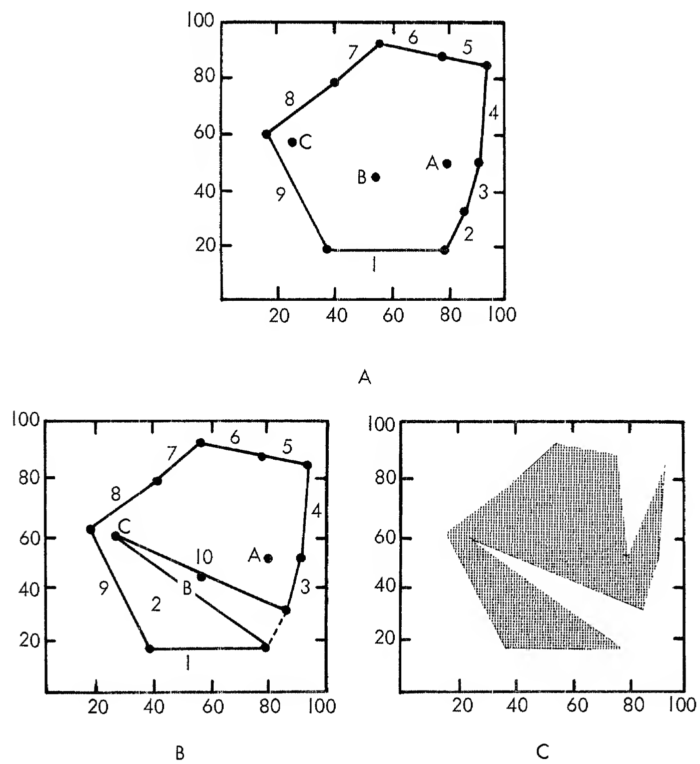


Fig. 8.1. Successive stages in the construction of a random figure according to Attneave and Arnoult's Method One. (F. Attneave & M. D. Arnoult. The quantitative study of shape and pattern discrimination. *Psychol. Bull.*, 1956, **53**, 452–471.)

While the foregoing description does not tell you what the other methods are like, it does give you the idea that a set of rules are developed and that the construction is made on a grid where positions are determined by the use of random numbers and the points are connected by rule. Some of the other methods also involve the use of random numbers and grids or matrices.

Fitts *et al.* (1956) described a method of generating classes of figures that can be described precisely in probability terms. These they called metric figures. They then performed two experiments using such figures. The subject's task included speed in recognizing a given figure when presented as one of several alternative figures. They found that figures generated by a random process were detected much more quickly than by those generated by sampling contour details without replacement. This they interpreted as showing a detrimental effect of a particular kind of redundancy rather than of a decrease in information per se. After some training, symmetrical figures and vertically oriented ones were detected more quickly than were single or double contour asymmetrical ones or horizontally oriented figures of similar complexity.

EXPERIMENTAL WORK

Mach's experiments

Mach (1914) used a revolving drum on which was fastened a white paper containing a series of tapered areas of black, as in Fig. 8.2. When

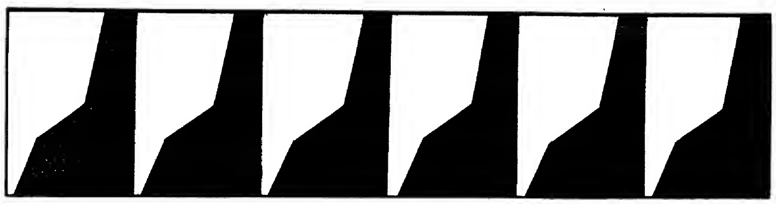


Fig. 8.2. Mach's figure. (E. Mach. *The analysis of sensations.* (5th ed.) S. Waterlow (Trans.). Lasalle, Ill.: Open Court Pub. Co., 1914.)

the drum was revolved rapidly, the observer saw the paper as a graded gray from one side to the other. The grays were in three steps as indicated in Fig. 8.3 in accord with lightnesses expected by Talbot's law. Photographing the moving drum showed the same result. The observer saw, in addition to the tapers just mentioned, two lines, one at each of the two junctures between the tapers. One would not expect them, for there were no reversals in the tapers whereby one ought to see a light area and then a dark area followed by another light area. Nor should he see a dark area and then a light area followed by another dark one as in Fig. 8.3.

Even when a pattern different from the first one was used in which there were no sudden shifts in shape, abrupt stripes or bands of gray were produced. Mach attempted to explain the effects by stating that what one sees is determined by the second derivative of luminosity (that is, d^2L/ds^2). This may be a statement of fact but a better approach is to go from there to a consideration of how the neuroretina operates. Fry (1948)

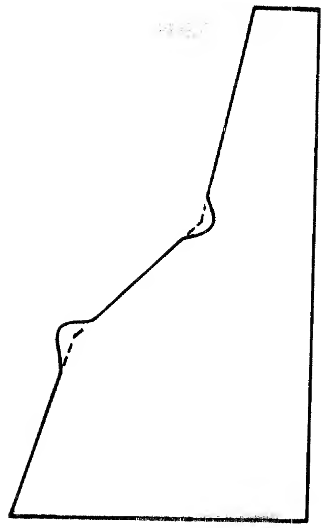


Fig. 8.3. How the visual system reacts to borders between various levels of illumination in Mach's experiment.

suggested an explanation in terms of neural interaction. Still other workers have made additional observations on what happens as certain of the stimulus variables are manipulated. Mach's experiments provide an example of how various workers have tried to get at the fundamental factors involved in the natural stimulation that results in the seeing of form.

Border interactions

Fry and Bartley (1935) used targets with components whose borders ran either parallel or at right angles to each other. Some of the borders were the bounds of areas such as disks and concentric bands or rings; others were portions of targets with straight sides. The phenomenon measured was the brightness threshold as borders were brought nearer to or removed farther away from the border of the test portion of the target.

A small area A as in Fig. 8.4 was surrounded by a broad band area within which was a thin ring. The ring was varied in its position so as to be either close to area A or farther away from it. The area between A and the ring was B, and the area beyond the ring was called C. The combined area of B and C was kept constant. As the ring was moved away from A, the differential threshold between A and B was lowered. It was concluded that the inner border of the ring was the influencing factor. Thus, it could be said that a border parallel or concentric to the border of the test target raises its differential brightness threshold.

In an earlier experiment by Blachowski (1913) in which the target was simply a disk with a surrounding band B, increasing the area of the bound

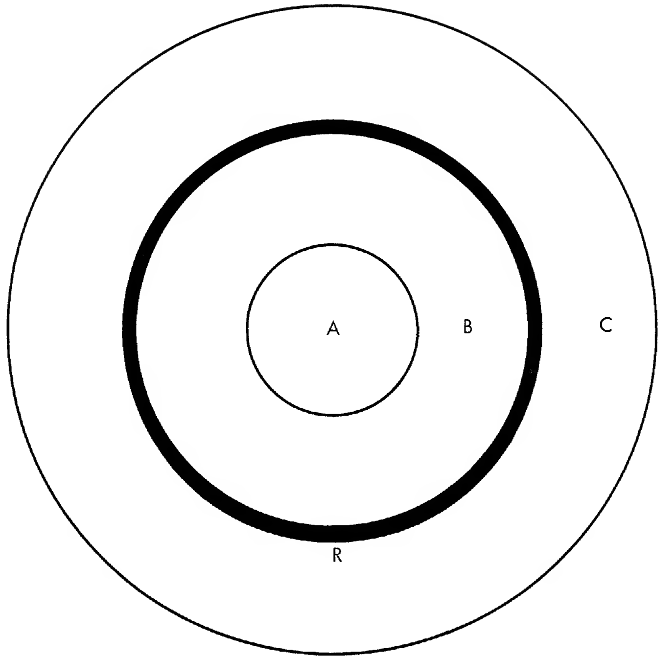


Fig. 8.4. Target of a central area A and a constant outer area B plus C. The distance of the border of the ring R from the border of A is varied. (G. A. Fry & S. H. Bartley. The effect of one border in the visual field upon the threshold of another. *Amer. J. Physiol.*, 1935, **112**, 414–421.)

lowered the differential brightness threshold between A and B. The interpretation for this effect was that the area B was responsible. That the combined area of B and C was held constant in the Fry-Bartley experiment seemed to rule area out as the causative factor in threshold reduction. This was the reason that Fry and Bartley took steps to manipulate distance between borders.

They went from there to other experiments in which borders not parallel or concentric but at right angles to the test component of the target were introduced, and they found that such borders lowered its threshold. The border that has an effect on threshold is often called an *inducing* border. The inducing border may not only be manipulated in distance from the test area border but may be brought into or removed from existence by luminosity manipulations of the area that it bounds.

Shape of test field

Lamar, Hecht, Shlaer, and Hendley (1947) investigated difference thresholds for rectangles varying from 0.5 to 800 square minutes of visual

angle, varying in length-width ratio from 2 to 200, mostly for foveal vision. Two widely different luminance levels were used, 17.5 and 2959 foot-lamberts. They found that when area adjusted to a critical value, with various length-to-width ratios, the relation between differential threshold and perimeter was invariant.

Sharpness of focus

Ogle (1960, 1961a, b) found that as the image of a test target is defocused, the difference limen between it and its surround is raised. The rate of rise in limen is smaller the greater the test target area and the farther the test target is removed from the fovea.

Discriminable differences in form

The study of detectable *differences* in form has been pursued in several directions, among which are the discriminations of threshold departures from squareness, threshold differences in rectangles, differences in curves of arcs of circles, differences in lengths of lines.

Veniar (1948) ascertained threshold differences in departures from squareness. She used four basic squares with sides subtending visual angles of 7.84°, 3.92°, 1.96°, and 0.98°. For each square, various rectangles were made by adding to or subtracting from either the vertical or the horizontal dimension of the square. The squares were presented tachistoscopically for 2 seconds with 8-second null periods between. The method of single stimuli was used: Only one square or rectangle per trial was presented and the observer was to respond with a "plus" or "minus" in accord with whether a dimension was diminished or elongated. The differential threshold failed to vary systematically over the range studied (5.3 log units, from near absolute threshold to 100 millilamberts). No observer manifested systematic variation in his constant error in relation to conditions of stimulation. Nevertheless, the Weber fraction for this discrimination of shape distortion for all sizes of squares used was, on the average, 0.014 of the standard side.

Bühler (1913) studied the differential thresholds for rectangles. A fixed rectangle 340 by 255 millimeters was shown on a screen as a shape reference. A variable rectangle with a base of 600 millimeters and height of from 535 to 650 millimeters in steps of 5 millimeters was shown as the comparison shape. Each trial consisted in presenting the standard and 2 seconds later the comparison. Each was shown for 0.75 second. The observer was given three choices, "slimmer," "the same," and "wider." The outcome in terms of Weber fraction was close to Veniar's: 0.013.

Bühler also determined just-perceptible differences in the curvatures of arcs of circles. An angular unit in dealing with circles is the *radian*, the

angle subtended by an arc of a circle equal in length to the radius of the circle. The curvature of an arc, measured in radians per unit arc, is the reciprocal of the radius. In one experiment, Bühler found that an arc of 80-millimeter radius was perceptually different from one of 82 millimeters. The Weber fraction would be 0.025. The detection of differences does not depend alone upon the differences in the arcs themselves but also upon their lengths, their mutual positions, the differences in the luminances of the arcs and their backgrounds, and even in the thickness of the lines constituting the arcs.

The discrimination of differences in lengths of straight lines was studied by Kiesow (1926). The lines were from 10 to 300 millimeters in length and were viewed from 40 centimeters. They were 0.33 of a millimeter in width. The Weber fraction was found to vary from one end of the range of lengths to the other. For a 10-millimeter line, the fraction was 0.0105, and for the 300-millimeter line it was 0.0066.

Hamilton (1929) found that indicating to the observer that he has made a response lying within certain narrow limits of error tends to improve his performance. Performance can also be improved by indicating a certain degree of error.

Detection of form in a complex field

Another sort of problem in connection with perception of figures is identification. This problem can be attacked in several ways. Boynton (1957) had the observer identify certain targets in the midst of an array of irregular shapes with which the test target might be confused on account of some degree of similarity. He used six classes of test targets with five members in each class. The classes consisted in five different pentagons, five irregular crosses, five quadrangles, five "nonsense" shapes he called nothingons, and five irregular Y-shapes. The shapes used as the array in each case were called struniforms and were irregular shapes with no angles or corners, all the protrusions and recesses being curves (Fig. 8.5).

The percent for correct identification of the presence or absence of the test target within an array of struniforms was ascertained as dependent upon target contrast, exposure time, distance between the observer and the array, and the number of struniforms in the array. It was found that correct identification was dependent upon contrast up to 40 percent, beyond which the two were independent. For arrays of 256, 128, and 64 struniforms, correct identification increased markedly with increases in exposure time. For smaller arrays (32, 16, 8), correct identification increased only slightly as exposure time was lengthened.

The factors involved in controlling correct identification possessed an interchangeability. For instance, if exposure time and the number of struniforms in the array were multiplied by the same factor, the percent correct

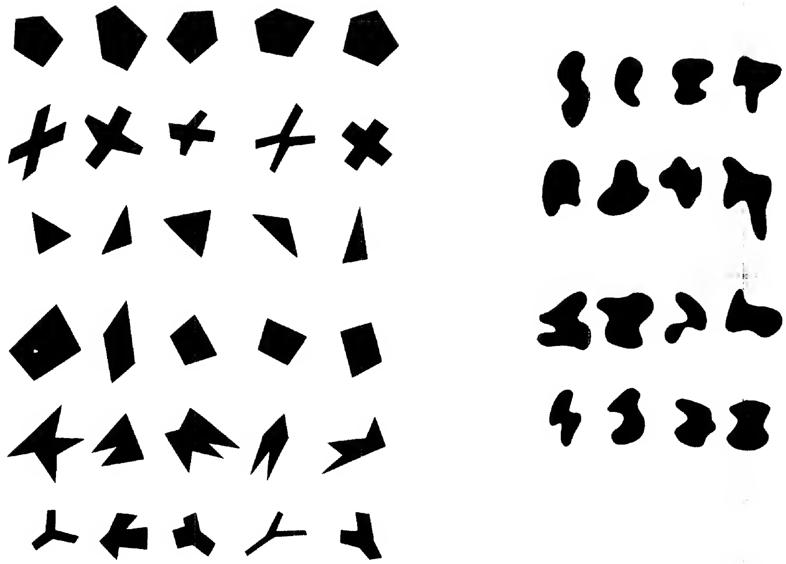


Fig. 8.5. Forms used to study detection of forms displayed in arrays of irregular shapes, shown in the group on the right. (R. M. Boynton. Recognition of critical targets among irrelevant forms. In J. W. Wulfech & J. H. Taylor (Eds.), *Form Discrimination as Related to Military Problems.* Washington, D. C., National Research Council, 1957.)

identification remained unchanged. Percent correct identification and distance of observation were inversely related up to 30 meters.

Factors for and against perception of areas and edges

When the photic radiation reaching the eye from certain portions of the visual field differs from others in amount, the observer usually perceives areas of different levels of lightness. Many of these areas will be perceived as *objects* with abrupt edges, although this need not always be the case. At other times, when the *spatial* features of the stimulus involve marked intensity contrasts, but the timing of the successive components of the target's presentation is altered, that which was seen as a sharply bounded area loses its edges and entirely disappears. In other instances, perceived areas lose their sharp edges and shift to areas of tapered brightness or grayness, with indistinct or practically nonexistent edges. Here, again, it is sometimes a matter of timing that is responsible. Thus, we may say that timing of stimulation is a crucial factor in the perception of surfaces and edges. As examples of this, we may turn to some experiments of Werner and of Bartley.

Werner (1935) presented pairs of targets of many forms varying from circles and disks to irregular and "incomplete" forms. In one case, for example, a target perceived as a solid black disk when presented alone was briefly presented on a light background (Fig. 8.6). In about 150 milli-

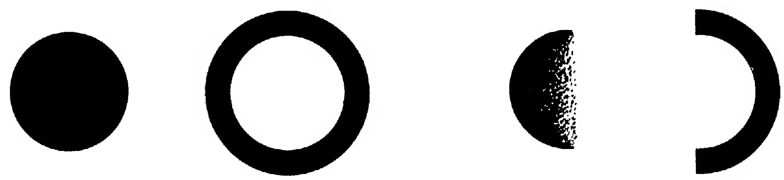


Fig. 8.6. Werner's figures. The disk and ring are presented in temporay succession, and because their centers are at the same point the disk occupies the same area as the space within the ring. Under some conditions, when half the ring is presented only half the disk is seen and then with a tapered gray surface, as indicated. H. Werner. Studies in contour. I. Qualitative analysis. *Amer. J. Psychol.*, 1935, 47, 40–64.)

seconds another target centered on the same point in the visual field was presented. When this target was presented alone, it appeared as a black ring. With the interval, as just specified, elapsing between the presentation of the first and second targets, the disk was never seen. This is to say, the area within the ring was not black. When the temporal sequences of the targets were reversed, the black disk *was* seen. The timing of the disk-ring succession that eliminated the seeing of the disk is more-or-less critical. If the rate of succession is slow, the disk will be seen to precede the ring. If more rapid, the ring is seen with a darkened inner field. If still more rapid, the inner field, which might have been expected to be a dark disk, lightens and may become lighter in some cases than the light field outside the ring. It is possible to interchange the intensity relation between disk or ring and the ground on which they are made to appear so that the figures become light and the ground black. In this case, the original phenomenon will still occur; that is, the object that ought to have emerged in contrast to the ground will not do so.

It will be noted that the second figure, a ring, had both an inner and an outer edge, whereas the disk, when it existed, had of course only an outer edge. Since the results differed in keeping with which of the two targets was presented first, they indicate that the outer border of the second target played a part in the outcome. The same results, it may be added, occurred whether both targets were presented in one eye or to separate eyes.

This may be what actually underlay the outcome. When the disk target is presented first but is followed very soon by the ring target, the border

contour for the disk does not have time to form. Since the contour process has not formed in the only time given it to do so, the ring simply develops as a ring without the disk ever being seen. At a critical stage in the decay of what was formed of the contour process for the disk, the contour process of the ring target may be able to utilize it to accentuate its own inner edge, for the directions of the two developing gradients would be the same. This account is based upon the principle originally recognized elsewhere in threshold studies that contour processes must develop and complete themselves before differences in brightness of two areas can be distinguished. Whatever depresses or precludes edge formation precludes the full appreciation of the brightness that the contained or adjacent surface would have.

We may continue with the account by detailing the possible process events when the order of target presentation is reversed. In this case, the temporal interval between the presentation of the two targets is not critical. Regardless of how soon the disk target is presented after the ring target, the disk appears as a black surface. This is to say that if the disk target is presented *before* the contour process for the inner edge of the ring is developed, it is simply forestalled and never completed, and the whole figure is seen as a large disk whose outer edge is the outer edge of the ring. If the inner contour process of the ring has time to develop, however, before the presentation of the disk target, this event, by changing the illumination within the ring, obliterates the condition for its continuance. That various contour processes in adjacent portions of the eye or nervous system interact with each other will be discussed in the section that follows.

Bartley's (1939) experiment had certain features in common with Werner's experiment. Bartley used a target arrangement that provided for seeing a figure of two parts: a disk that was surrounded by a ring whose inner edge was the outer edge of the disk. The stimulus flux for the disk could be alternated so that a light disk would alternate with a dark one, while being surrounded with a steady gray or only medium-bright ring. Raising the intensity level of the ring target above the mean value of the two alternating disks caused the light phase of the disk alternation to become less predominant than the dark phase. Reducing the level of the intensity of the ring target reduced below the mean caused the light phase to become predominant. Along with this shift in predominance, a difference in edge properties of the two phases of the disk developed. The predominant phase possessed a sharp edge; the "diminished" phase lacked an edge and became a mere tapered "shadow." The predominant phase seemed to occupy more time, thus taking up most of the cycle.

In order to subordinate the light phase of the disk and make the dark phase predominant, the intensity of the ring target (when alternation frequencies are low) had to exceed not only the Talbot level but the photic intensity for the light phase of the disk. Increasing the alternation rate reduced the level of the ring target needed until it reached Talbot level.

The light phases of the disk grew less bright as CFF was reached. To have the light phase predominate, the target conditions were reversed.

Robinson (1966) performed an extension of the general kind of inquiry made by Fry (1934), Werner (1935), and Bartley (1939), using three targets in succession instead of only two. In the earlier experiments, the one border of the first target was either identical to a border of the second target or as a variable the two were separated somewhat. In Robinson's experiment, the three targets were three disks, target I subtending 0.23°, target II 0.46°, and target III 0.92°. This of course meant that the borders were not identical. The observers were told that they would see target I, I and II, II and III, or all three. Each observer completed 400 trials, 50 at 25-millisecond intervals and 50 at each of the intervals 50, 75, and 100 milliseconds when targets I and II were used, and he completed 50 trials with each of the same four intervals between targets I and II when all three targets were used. Target III followed target II by a constant interval of 20 milliseconds. Of course, when only one target was presented, it was presented only once and so no interval was involved.

In the experiments prior to Robinson's, the second stimulus succeeded in making the first stimulus either less effective or noneffective. This was not originally called masking, but in recent years the word has crept in as a label for the effect. It is a very inappropriate word, for nothing that actually exists as a sensory effect here is *covered.* The first stimulus simply sometimes does not succeed in evoking a response. In Robinson's investigation, the attempt was to determine what sensory effects would be produced by the three-target succession, what "masking" would occur. The results showed a marked increase in the detection of target I when target III was included in the sequence.

For the intervals between targets I and II (when only the two targets were presented) that resulted in target I not being seen, the detection of target I became reliable when target III was used in the sequence. Target II was not seen on any of the trials when the three targets were used. Donchin, Wick, and Lindsley (1963) and Donchin and Lindsley (1965) have reported demonstrations of two-pulse ("flash") summation, resolution, and inhibition in human cortical evoked-potentials. Robinson (1966) feels that such work shows a basis for the effects he reported.

Form, intensity, and duration in the emergence of shape

One procedure in the study of the emergence of shape is to manipulate duration and intensity and geometry of the target. For example, if a subject is presented with a very weak photic stimulus—a target in very weak illumination—he will not see a well-contoured object. But as luminance becomes more intense, the target becomes more and more effective. A more detailed, highly differentiated perception is made possible.

Helson and Fehrer (1932) studied the role of form in perception. Their investigation was to determine the thresholds for seeing light itself and for perceiving just-noticeable form and definite form for six different targets, all equal in area. The targets were an isosceles triangle, a rectangle, a circle, a semicircle, an inverted-V figure, and a square. They were cut from low-reflectance cardboard and placed on the screen of a Nagel adaptometer, which is essentially a lamphouse with a large opal-glass screen, the intensity of which can be precisely adjusted over a very wide range. A fixation spot was used. With three observers, the three thresholds were obtained. With another observer, the procedure was simply that of increasing the intensity until light was seen and have him report on shape if it was discernible. If the target was undiscernible or if the observer was incorrect, he was instructed to continue increasing the intensity until shape could be seen and to indicate it and the certainty involved.

The three thresholds found in all cases were called the Light Limen (threshold), Form 1, and Form 2. The investigators found that in every case the thresholds for light were lower than for just barely perceived shape. The thresholds for light in the study were influenced somewhat by the geometry of the targets. It required about twenty-five times as much photic flux to recognize form correctly as just to perceive light, and twice as much flux to perceive shape in a vague way as just to detect light. The authors showed that shape perception is not primary, a corroboration of incidental observations in many routine experiences in precise laboratory work. Some target forms require less light than others to be recognized correctly. The rectangle, for instance, seemed to require the least among the six targets investigated. The thresholds and judgment of goodness of form of some of the other targets also differed.

> Some Os [observers] respond rather easily to the form of a stimulus complex and all that it entails, other Os do not respond at all, and still others (if the "trait" is normally distributed) fall in between the first two groups. How, then, is it possible to assert that form is a primary datum for all Os, that it is first in the history of the individual and the race, that it is constitutive in perception and behavior? Even under the conditions most favorable to form as such, i.e., when the Os were required to report the form seen, some Os fail to discriminate between forms or to be affected by the shape of the stimuli. Having found that it is impossible to set up criteria governing the effectiveness of form *qua* form, since various criteria give contradictory results, we now find that it is impossible to legislate for all Os regarding any influence of form whatsoever since some Os are apparently unaffected by differences in forms, even when set to observe them. We are, therefore, forced by our experiments to deny that the factor of form is always or even, as Köhler has tried to ameliorate the generalization, "the most important property which a whole may have." It may be a determining factor for some individuals in some types of experiment, but this is different from the assertion that it is the primary or most important con-

> dition in perceptual behavior. The broad generalizations respecting the role of form in perception made by the configurationists constitute another example of the fallacy of generalizing from "some to all." (Helson and Fehrer, 1932.)

This statement would make it appear that the matter of shape in perception is a developmental achievement. First, shape is not primary—that is, the very first something that is detectable is too vague and diffuse to be described in terms of shape. Second, all persons do not achieve the same ability to perceive shape under a given set of threshold or slightly supra threshold conditions.

If three-dimensional targets, under moderate illumination, are presented for increasing lengths of time, beginning with about 0.01 second, the objects seen are quite vaguely defined and are two-dimensional rather than three-dimensional. As more and more time is put into the presentation, more and more details are recognizable, and the two-dimensionality shifts into three at some given point. The identity of the object also changes. Even though throughout a given range identity may be fairly certain, the ultimate identity, when longer stimulation is given, will differ and provide the observer with the maximum certainty—the kind usually experienced from day to day in seeing familiar objects.

Casperson (1950) investigated the discrimination thresholds for six geometric forms (an ellipse, a rectangle, a triangle, a diamond, a cross, and a star) and related their discriminability to three of their quantifiable features. Five different variations of each of the forms, equal in area but different in maximum dimension and perimeter, were utilized. Each form was then reproduced with total area as a variable. Thus, there were six forms, five variations in each, and seven different sizes or areas for each form. The forms were presented nine at a time in random order for each area. The subjects called off the names of each of the areas on each card, viewed from a distance at which some confusion between forms was possible. It was found that area was the best measure of discriminability for ellipses and triangles. The maximum dimension was the best measure for rectangles and diamonds. The perimeter was the best measure for stars and crosses. Prediction of discriminability for the forms was best achieved on the basis of their perimeters. It was found that the circle and the ellipse were not easy to identify. As a consequence, the results show that the Gestalt principle of simplicity is not a sufficient predictor of the relative discriminability of the forms used in the experiment. The variance due to form differences was greater than the variance among the twenty observers, substantiating the idea that forms do differ significantly in their discriminability. This was another example of the studies in which the Gestalt theory of "good figure," or "simplicity," was disproven. Helson and Fehrer (1932) had shown that the rectangle and triangle ranked ahead of the circle in perceptibility. Similar findings were reported by Collier (1931) and

Munn and Geil (1931). The exact order varies in the studies, but the circle did not turn out to be the most perceptible form.

One study, that of Hochberg, Gleitman, and Macbride (1948), offered some evidence that the circle had the lowest threshold of discriminability. The forms tested were a circle, a rectangle, and a block cross, all of equal area. One defect in this study was the use of so few forms. There was no report of frequency of reporting the different figures regardless of accuracy. A strong tendency to report circles whether accurate or not would make the circle seem to be superior.

A matter at issue in dealing with form is the fact that the Gestalt school asserts that all experience is formed and so form is primary in experience. Various workers seem to have cast considerable doubt on this principle. The work of Helson and Fehrer in which they found three levels of perception shows the untenability of the primacy of form, and the studies of several others—Brigden (1933), Brown and Niven (1944), Dickinson (1926), and Zigler, Cook, Miller, and Wemple (1930)—run in the same direction.

Relation of form and brightness

Hanes (1950), cognizant of the question of the possibility that forms vary in their discriminability, and cognizant that the work already done had not absolutely confirmed which form among the common ones was superior, felt that perhaps certain controls had not been duly observed. Consequently, he undertook to study the relation of form to the perception of brightness. He thought, for example, that if "compactness" were a factor in form detection at threshold, it might be a factor in determining perceived brightness.

The targets for Hanes's study were circles, triangles, and squares. Each was presented in three different areas—0.0031, 0.0123, and 0.7854 square inches—and viewed at a distance that resulted in the forms subtending visual angles of about 9, 18, and 144 minutes, respectively. Three luminosity levels were used: 0.1, 10, and 100 millilamberts. The forms were made by showing the proper masks on an opal-glass screen. Two of the three forms were presented at a time, one being a standard and the other one whose brightness was to be adjusted to match the standard. The standard was used both on the right and on the left. Hence, the factors were: the number of combinations of two forms at a time (6) $\times$ 3 levels of luminosity $\times$ 3 areas $\times$ 2 positions for pairs in each combination both as standard and variable, making 162 comparisons. There were five observers. In all trials the area of the two forms were the same.

The results showed that the triangle and circle manifested a greater brightness than the square. The differences varied for the areas and for the luminosity levels. There were some significant interactions among the three

factors. For the two smaller areas, the triangle manifested consistently higher brightness than the two other forms. For the largest area, the circle appeared to be brightest. No simple, single explanation was given for the results. The results suggest, however, that with comparisons such as we described in the previous investigations, one should take luminosity into consideration so as to equate for perceived brightness. This has not been done; it would be interesting to discover what difference this would make in discriminability.

Relation of form to phenomena obtained with stabilized images

In Chapter Three on visual acuity you first came upon the discussion of stabilized images on the retina. Pritchard (1961), studying stabilized images, found that the alternate disappearance and reappearance of objects when their images were stabilized depended upon the character of the image itself. His data tended to support to some extent the "cell assembly" theory of Hebb (1949), which states that perception is based upon certain potentialities of the nervous system. A pattern is perceived through a combination in the brain of separate simple neural impressions already produced there. These form more or less the elements of the pattern in question. Thus the perception of the pattern is in part a result of very simple kinds of initial neural activities combining to give the ultimate result. Pritchard's data also supported the configurational idea of certain kinds of innateness in the determination of perception. It is difficult to provide a sophisticated statement of the matter that would contain enough specificity to make the two ideas concretely testable beyond the very general ways already exemplified. We can, however, describe some of Pritchard's findings.

With the kind of stimulus instrumentation described in Chapter Three, the observer initially sees an object located at an apparent indeterminately great distance. Its image subtends a visual angle of 2° in an illuminated surround of 5°. The area peripheral to this is unilluminated. After a few seconds, the object disappears progressively but not by gradual dimming. A gray field is left and this may soon darken to an intense blackness.

If the target is a single line, the line vanishes rapidly, and when it reappears it is the initial total line. If the target is more complicated, it may or may not disappear as a total. It oftens disappears by parts, each of which vanishes independently. The time taken for overall disappearance is some function of the target's complexity. The fraction of the overall observation time during which a single-line figure is visible may be only 10 percent whereas a more complex figure may be visible for 80 percent of the time.

The line-drawing of a human face will tend to disappear in meaningful units rather than in an indiscriminate fashion. That is, a nose or a mouth

will disappear as a whole. One needs to realize, however, that this is not necessarily quite what seems to be implied, for actually the elements of a mouth or a nose are closely adjacent parts in such a target, with considerable unstructured area between them. What can be said with most certainty is that the pattern does not disappear by homogeneous or overall fading but in patches, and these patches happen to be meaningful units in the line-drawings used by Pritchard. He did not use "half-tone" (photographic) targets in which there are graduations of luminosity, but something approaching half-tones was tested when an irregular ameba-like structure was partially "obscured" by cross-hatching. The ameba or the cross-hatching would disappear independently. This result does not quite tell whether the cell-assembly principle determined this functional cleavage or whether it is a demonstration of the configurational theory. It would seem likely that somehow both are involved. If so, then the isolated advocacy of either one is a kind of distortion of the real dynamics of the matter. Sometimes two parts of a figure seem to lie in separate planes. And, when parts of the ameba-like and the cross-hatched portions of the figure disappear together, the remaining portions seem to constitute a "hybrid" or new unitary figure more unitary than the initial ameba and cross-hatch. Sometimes when the ameba figure is presented alone, it undergoes "simplification" in which some of its bulges or pseudopods disappear to be replaced by what Pritchard calls an hallucinated seal-off of the gap by a direct line. The new figure is a simpler one, more nearly devoid of irregularities.

Pritchard points out that most figures are seen as three-dimensional when viewed with a stabilized image. The line-drawings may tend to appear as "wires" suspended in space. One example of three-dimensionality is illustrated by a hexagon target, which appears as a cube in three dimensions. That reverses in the same way as a Necker cube. The Necker cube is an outline drawing of a transparent cube viewed obliquely. Thus all of its edges are seen. The front and back surfaces appear to interchange. Thus it is an example of reversible perspective.

Curiously enough, a solid square (not an outline) fades inhomogeneously. It fades at the center, doing away with one corner after another. Those that remain are still sharply outlined. This phenomenon does not seem to be very good evidence for a simple configurational theory, for, although a square is not the simplest figure known, still it is a figure or definite configuration, and it disappears and reappears as a unit.

Perception of hidden figures: the roles of overlap and context

Ghent (1956) showed a series of overlapping figures, each being an outline drawing, to ninety-nine children of from 4 to 13 years of age. Almost

all the intended figures were reported. Omissions were small even with the younger children and decreased in number with age.

In the second part of the investigation, certain distinctions were made in the material presented. Comparisons were made between "realistic" and geometrical figures and between overlapping and embedded figures. In this study, thirty-four children between 4 and 8 years of age were tested. For overlapping figures of both types (realistic and geometrical), omissions were few even in the youngest children. Significantly more omissions were made on the material with embedded (or hidden) figures than with overlapping ones. Performance was progressively better as age increased.

Ghent concluded that when a figure is hidden by other forms whose boundaries partially coincide with the figure to be detected, it is more difficult to isolate than when the hiding of the figure is accomplished by overlap, or mere intersection of the lines describing the other forms. Ghent concluded that if this is the essential feature in distinguishing the two tasks, then improvement with age reflects an increase in the ability to perceive a boundary as belonging to more than one figure.

Embedded figures were studied by Crudden (1941) in 6-year-olds. She found that symmetrical figures were more easily detected than asymmetrical figures. Meister (1949) found that the preschool children were better able to discriminate figure from ground than to detect geometrical forms per se. Witkin *et al.* (1954) found that in what might be called "part-of-a-field" tests, the perception of an item was greatly influenced by the nature of the surrounding field. This influence greatly decreased up until the age of 17, beyond which there was a reversal toward field dependence. Fraisse and MacMurray (1960), dealing with field-dependence, reported that as children grow older thresholds are lowered for words but not for other items such as objects. Gibson and Walk (1956) found that children become differentially sensitive to various items, particularly those they encounter in early life.

Figural after-effects

A second target appearing in the visual field at the place occupied by a previous one will be differently seen than if the previous target had not been presented. This holds only under steady fixation, for if the eyes move then new parts of the retina will be involved and the conditions of stimulation just implied will not be satisfied. Various examples of this effect, the *figural after-effect*, are to be found in the literature, some prior to any extensive study of the matter. Gibson (1933), for example, observed that if one fixates a curved line such as an arc of a circle and is afterward presented with a straight-line target, the line will not look straight but will be curved in the direction opposite to that of the arc. Another effect in the same category is produced by the presentation of a tilted line (Vernon, 1934;

J. J. Gibson, 1937; Gibson and Radner, 1937). If one views a line tilted away from the vertical, say to the right, and then looks at a line otherwise seen as vertical, the second line appears to be tilted away from the vertical to the left.

Various target arrangements have been used to study figural after-effects, and various sense modalities have been examined to determine whether figural after-effects could be found in them. Figural after-effects in the sense of touch is one notable example that was found.

The factors such as temporal variables involved in producing figural after-effects have been subjected to various manipulations. The time of figural after-effect disappearance after the inspection period and the development of after-effect as a function of the duration of the inspection period have both been examined. The inspection period is the time spent fixating the first target. In fact, timing of all the elements in the experimental sequence is somewhat critical. When a curved line is fixated, it looks less and less curved as fixation is continued. When a straight line is presented immediately afterward, the line looks curved in the opposite direction. Using a compensating curvature for the second line allows its manipulation so as just to prevent the second line from seeming curved at all. One can quantify the need for compensating curvature and thus have a measure of the effect produced by the inspection target for given durations.

Displacement is also a factor in figural after-effect and can be illustrated by the target arrangement of Köhler and Wallach (1944) in Fig. 8.7. The solid rectangles in A constitute the inspection figure when fixation is at point X. After about 40 seconds of fixation, the target arrangement is replaced by a new (Fig. 8.7*b*). The target elements in the right column (T^2 and T^4) are brought closer together and the elements T^1 and T^3 are made farther apart. This is called displacement and the action may be stated as follows: Any border subsequently presented a short distance from the location of the border of the inspection target will be displaced away from the region where it was. This effect first increases with distance and later decreases.

The magnitude of the displacement is also affected by inspection duration. Hammer (1949) found that the displacement increased with inspection duration to somewhere between 40 and 100 seconds and then became constant.

The time interval between viewing the inspection target and viewing the test target was studied by Oyama (1953) and Ikeda and Obonai (1955a, b). Periods between zero and 125 seconds were used. It was found that the after-effect decreased with increase in the interval. The rate of decay varied directly with the duration of the inspection period. Inspection periods of one to 240 seconds were used. With short inspection periods the rate of decay was extremely fast. Hammer's findings, that the length of

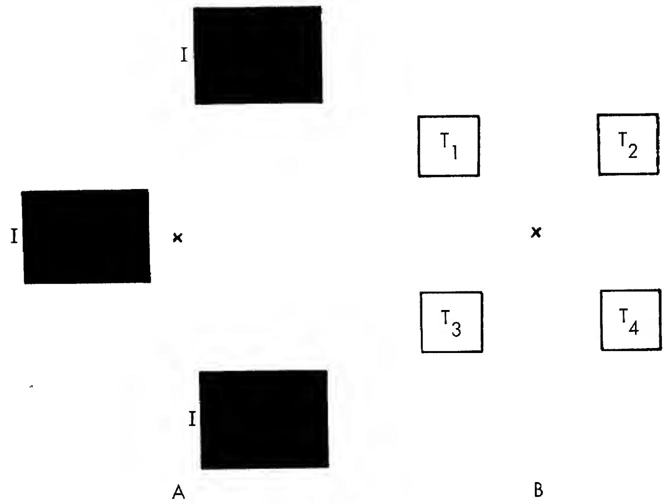


Fig. 8.7. Arrangement to demonstrate figural after-effects. (W. Köhler & H. Wallach. Figural after-effects: An investigation of visual processes. *Proc. Amer. Phil. Soc.*, 1944, 88, 269–357.)

inspection period definitely affected displacement, was not confirmed; differences in methodology may account for this. Hammer used the method of average error while the Japanese used the method of constant stimuli.

In certain cases there seems to be a connection between figural after-effects and geometrical illusions. For example, in the concentric-circle illusion, the small circle existing alone seems to be smaller than the metrically equal inner circle in the second figure. Obonai (1952) pointed out that the after-effect, which is a successive event, approaches the illusory event, which is simultaneous, as the temporal interval between the inspection period and the test period is reduced to zero. Thus, it would seem that the two cases belong to the same class of events.

Another example of the same thing may be the phenomenon studied by Brown and Voth (1937). They used four luminous targets (disks) forming the four corners of a square presented in sequence and, as the rate was speeded up, the event seen was first a luminous line nearly in the shape of a square; as velocity increased the line became progressively more and more nearly a perfect circle, but it contracted so that the circle was definitely smaller than the near-square had been.

A great deal of attention was given by Köhler (with Wallach, 1944; with Emery, 1947) to examining figural after-affects. He resorted to what was called satiation, a kind of physical principle. (Whatever this principle is and whether it operates here or not, it had better be given the name of *saturation*, a word applied in chemistry and physics, rather than *satiation*

a word applied to human behavior such as appetite.) In the satiation theory, the brain is taken to be a quasihomogeneous conducting mass. Stimulation results in depolarization, which in turn leads to flow of electrolytes, which limits the effect of successive stimulation. The model is made to do pretty much what the investigator wants it to do. One of the chief arguments against the theory is that it totally neglects the citoarchitecture of the brain and the details that would be determined by neuron activity with its inhibition-facilitation processes as already known to neurophysiologists. The theory seems to be more attractive to psychologists than to neurophysiologists.

Osgood and Heyer (1952) were not at all satisfied with the Köhler and Wallach interpretations and made some suggestions of their own. They pointed out that all behavior is of course mediated by certain neural and certain motor processes. The central neural processes are very complicated and can be viewed not only from the standpoint of the specific elements of which they are composed but from an overall "field-like" position as well. But this position must take into account certain neurophysiological facts. For instance, it has never been possible to show that various neurones affect each other except through synapses. Only at artificial synapses (ephapses at the nodes along axons) have there been any demonstrated additional interactive points. The nature of the interaction between neural elements must be taken into account in constructing theories about how the system operates and thus how figural after-effects are produced.

The fact that neurophysiologists had not yet provided a satisfactory model of how the network produces figural after-effects, in terms of known neural activity, did not give Köhler and Wallach justification to set up a novel and entirely nonneural scheme. Osgood and Heyer, taking account of what was known regarding neural activity, proposed what they called a statistical theory of the operation of the visual projection system to account for the after-effects. This theory consisted of six assumptions:

1. A seen edge of a figure is represented in the visual projection cortex by a normal distribution of neural excitation. This extends throughout the length of the contour as a "ridge."
2. The distribution of neural excitation in the projection area is determined mainly by "on-off" fibers.
3. The rate of excitation of the process-complexes responsible for seen edges varies directly with the abruptness of intensity gradients in the retina and their nearness to these gradients.
4. Under steady fixation of a target, cells in the projection area carrying on the "on-off" activity become differentially adapted as negatively accelerated functions of the *rate* at which they are activated and the *time* through which they are activated.

5. The adaptation gradient flattens out during periods of recovery, supposing prior adaptation is a negatively accelerated function of its magnitude.

6. The location of an edge in visual space coincides with the location of maximal excitation in the projection area.

It is too complex and extended a task to show here how Osgood and Heyer think this theory applies to the various phenomena of visual effects. The essential thing that can be said for the theory, however, is that it attempts to utilize what is known about neurophysiology rather than abandoning it. The theory contains some of the faults we have already pointed out about copy theory and, therefore, cannot begin to be taken literally as a construction to relate visual phenomena to the spatial features of brain activity. This means that at present we have no complete and satisfactory neural model for accounting for figural after-effects or any other visuo-spatial phenomena.

Lashley, Chow, and Semmes (1951) taking the Köhler-Wallach theory seriously for the moment, attempted to put the theory to experimental test. Gold pins were embedded in the cortex of one monkey and on another gold sheets were placed on the cortical surface in the occipital lobe. The animals manifested no impairment in pattern discrimination whereas they should have had the physical principle asserted by Köhler and Wallach been the basis for visual after-effects.

McEwen (1959) was concerned with the fact that the experienced size of an after-image depends upon the size of the area of the retina that has been adapted to the target and on the distance of the surface upon which the image is projected. Emmert's law pertains to the dependence on distance. Eidetic images are supposed not to conform to Emmert's law. The question has been raised as to whether figural after-effects have an absolute size as is claimed for eidetic images or are governed only by the size of the adapted ("satiated") area on the retina or whether they behave like after-images.

Prentice (1947), after viewing the inspection figure to produce adaptation ("satiation"), varied the distance at which the test figure was placed. He found that the apparent size of the test figure remained the same at different viewing distances. Because at the greater distances the retinal image produced by the test figure on the satiated area is smaller, and its contour is objectively further from the inspection figure, and because no differences were obtained in the after-effects, he concluded that apparent size determined the magnitude of the after-effects. This is a curious conclusion, because apparent size is one feature of the after-effects. To make a feature of the effect be a part of the cause does not seem valid. Prentice (1950) later continued his investigations.

Hochberg and Bitterman (1951) also studied after-effects, including

a measure of their displacements. This was followed by a study by Sutherland (1954). Various Japanese, including Ikeda (1951), Ikeda and Obonai (1955a, b), Motokawa, Nakagawa, and Kohata (1957), Oyama (1952, 1954, 1956), and Sagara and Oyama (1957) have also studied figural after-effects.

Illusions

The perception of objects and shapes elicited by various figures and forms, especially those drawn on plane surfaces, manifests many complexities, surprises, and superficial contradictions. Many shapes that are seen do not tally with the measurements in the targets used to elicit them. Such discrepancy is called illusion. The implication in using such a label is that what is seen is not real. Various criteria for reality can be used and it is in accord with the criteria employed, whether or not the perceptions are mistaken and unreal. Whatever conception is to be used in dealing with perception as a phenomenon of natural science, the idea of unreality and mistakes must be ruled out.

Once the mechanisms of vision have been discovered the "illusions" as well as other phenomena will be accounted for. There have been in the past several classifications of illusions and apparent explanations of them. The trouble is that the explanations have been too numerous and no one explanation has accounted for very much. The ideal would of course be to have one explanation that would handle all the cases.

Figure 8.8 depicts four of the classical illusions. Some of them are well known to everyone. Experimental work in the study of illusions has concentrated on only a few problems. One is the question of whether given illusions can be eradicated in perception by training (the question of the types of training is a variable).

Another question has been the relation of the magnitude of certain illusory effects to age. The illusions studied in this way have included the Delboeuf illusion, the illusion of parallel lines, Titchener circles, the size-weight illusion, the Müller-Lyer illusion, and the horizontal-vertical illusion. The Müller-Lyer illusion seems to have received the most attention, with the horizontal-vertical possibly next. The others have been studied by two or more workers. Most illusory effects seem to decrease with age; a few increase. In fact, different workers, studying the same illusion have obtained opposite results, which suggests that conditions involved in experimentation or taken into account in the collection of data must have differed.

Some see illusions as cases of "misapplied constancy" effects (Teuber, 1960). Classical geometrical illusions have been classified as involving visual extents and angles. Many patterns involve both. Oppel (1854–1855), for example, demonstrated that interrupted lines are overestimated. Wundt (1862) pointed out that vertical lines tend to be overestimated in com-

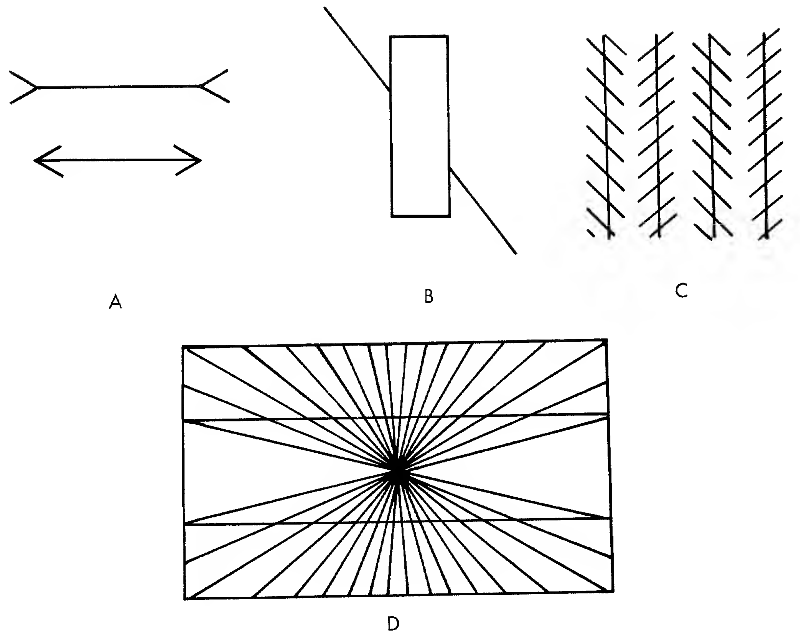


Fig. 8.8. Some classical illusions: A, Müller-Lyer; B, Poggendorf; C, Zöllner; and D, Hering.

parison to horizontal ones. Zöllner (1860) dealt with variations in the perception of angles. It seems that the various analyses in the literature simply make statements of simple facts or simple suppositions and do not constitute theories that explain much.

We would suggest that drawings made on a two-dimensional surface can be regarded either as arrangements in a plane or as representations of a three-dimensional situation. It so happens that not all two-dimensional arrangements of lines represent consistent three-dimensional shapes or objects. When they do not, the arrangement as a total becomes illusory. To make the critical component nonillusory, the overall figure must be broken into components. Each component will represent a three-dimensional construct. Take as an example the Poggendorf figure pictured in Fig. 8.8; the diagonal lines, from a geometrical standpoint, actually form a continuous straight line when connected, but they appear not to. However, if one regards the vertical columns or rectangles as standing erect and the lines as forming a horizontal structure extending away from the viewer, then the lines are parts of a single straight line. The illusion vanishes. Some observers have some difficulty in seeing the figure as a three-dimensional representation; when they do finally so see it, the results are as stated.

Take the Zöllner's figure in Fig. 8.8 as another example. The vertical

lines do not seem to be parallel and so look to be different from what metric measurements tell us they are. In the figure, the total is an inconsistent construct. One can resolve the illusion by segregating components of the total and viewing them one at a time. If one looks at the first two vertical lines and the short diagonal lines that cross them as representing a three-dimensional situation, then the vertical lines become parallel. This principle cannot be applied when one is looking at the total figure, because as a total it is not consistently structured to be a simple, natural three-dimensional situation. The principle just stated can be applied to other figures.

Let us next try the Müller-Lyer figure. The lower horizontal with its turned-in angles looks shorter than the upper one with its turned-out angles. If one regards the two horizontals as part of a perspective (that is, a three-dimensional situation), the two lines are properly seen to be equal (that is, as *representing* equal extents as seen in a vertical three-dimensional situation). This brings up the distinction between *being* and *representing*, the same principle involved in perceptual constancy when we say that a man 200 feet away *looks* the same size as when he is 50 feet away. Literally, one can think of the relative space he occupies in the overall visual field in the two cases and have to say that it is not the same.

If one puts the upper line with its turned-in angles below the other line, two results are possible. The illusion in line length remains when one looks at the total structure representing a surface extending away from one, as seen from above. If one looks at the surface as seen from below it, then the two lines can be seen as representing equal extents.

It would seem that in one way or another the question of three-dimensionality always enters in viewing a line drawing on a plane surface. In dealing with illusions, one must deal with the question of representation. What is it that one is looking at? And this is determined in part by the viewer and in part by the geometry of the structure. The discussion may fall far short of a satisfying explanation of illusions, but it represents a step ahead by recognizing the ambivalence in two-dimensional figures and that the tendency to see them three-dimensionally is easily possible. It is possible, too, that the tendency we possess is somewhat culturally determined, so that we might approach the solution of illusions quite differently if a cross-cultural investigation were to be made with the principle just discussed as the motivating idea.

It is not that we insist that all two-dimensional drawings tend to be seen as representations of three-dimensional situations. We certainly do not. One's habits are not that completely unidirectional. What we have just said can be rephrased by saying that in nonpicture situations the organism is differently faced with the problem of three-dimensionality and has both phylogenetically and ontogenetically developed modes of doing so in keeping with the most persistent features of the environment. Once

he is brought to dealing with geometrical forms drawn on a two-dimensional surface, he is to some degree dealing with *representation,* the business of having something two-dimensional look either two-dimensional or three-dimensional. The student of visual behavior should take this into consideration. If and when he does, it is likely that he will come closer to accounting for certain characteristics of the drawings. It does not seem that classical theories and explanations of illusions take this matter into account.

SUMMARY

The first division of this chapter on figure and form presented several preliminary considerations, such as the concept of *target* and the distinction between it and the concept of stimulus; the uses of the words outline, edge, border, and contour; and ways of specifying target shape.

The remainder of the chapter was given over to the presentation of a variety of experimental approaches to the study of figure and form, beginning with Mach's classical experiment on the emergence of edges in a minimally structured field. Other matters presented were the shape of the test field (target), sharpness of focus of the retinal image, detection of forms in complex fields, the roles of form, intensity and duration in the emergence of shape, the effects of stabilized retinal images, and perception of hidden figures, figural after-effects, and illusion.

NINE

Perception of Movement

Movement as a term is commonly used in two contexts. One is the environment where specifications are geometrical and have to do with the convention of physics. The perceiver is omitted in reference and the term pertains to matters outside the perceiver and the introspective and experiential domain. The other context is experience and animal behavior, in which the experiencer *sees*, *hears*, or *feels* something he calls movement or in which the animal acts as though reacting to physical displacement.

In the present chapter, we are interested in the latter reference—in the perception of movement. It has become conventional among psychologists, particularly in referring to what is seen, to call seen movement "real" when it is produced by physical movement (or displacement) and to call seen movement that is produced without displacement "apparent movement." The words *real* and *apparent* do not seem to be appropriate, however, for facts in both the physical and experiential domains are "real." But as much as we should like to dispense with the way this dichotomy is labeled, we may have to abide by it here.

There are many forms of the perception of movement. The two main classes are the experience of (1) the movement of the person himself and (2) the movement of something external to the person. Both forms may be produced by stimuli undergoing displacement or by stimuli that are stationary.

Various sense modalities participate in the experience of movement: conventionally speaking, there are visual movement, kinesthetic movement, movement based in part on the action of the vestibular mechanism, tactual movement, and auditory movement. There are some forms of movement

that we shall deal with elsewhere. The major considerations in the present chapter are those of visual, tactual, and auditory movement.

Among the great variety of phenomenal movements that the normal person may experience is the kind illustrated by the following. If a person looks steadily at a vertically moving belt on which there are seen alternate transverse stripes of white and black, he will see that the bands continue to move for a short time after the belt is stopped. Although the best experiential description is certainly that of movement, it can be said that the stripes do not go anywhere. But since the stripes do not actually behave so that one can clearly follow their displacement and progress, the movement experience is not in the fullest sense a *spatial* phenomenon. On the other hand, it is undoubtedly a sequential one. It is the experience of something happening in time. Thus, we have a visual experience that lies on the borderline of not being spatial according our discussion of space perception in Chapter Seven.

VISUAL MOVEMENT

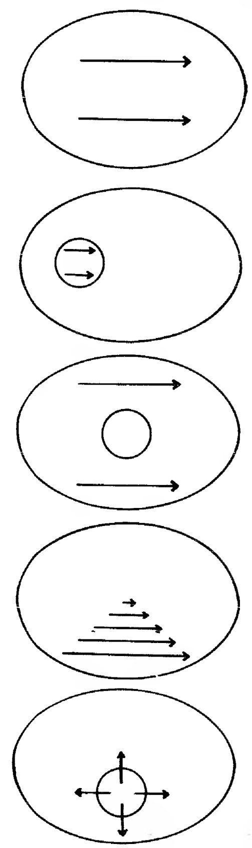
Real movement

Real movement is the experience of movement based upon something being displaced in the world outside the observer or it is the experience based upon the displacement of the observer himself in a stable environment. Displacements like these involve displacements in the images on the retina.

It is appropriate to classify the kinds of image displacements that may occur, for they are not all of one simple sort. The diagrams in Fig. 9.1 show the various essential forms of displacement of images on the retina. The first of the five forms is the whole-field image that moves by short jumps across the retina, such as occurs in the unwitting jumplike eye movements in reading a line of type. With this form of image displacement, there is no experience of the external environment during these jumps (saccades), hence there is nothing to specify as either in motion or not in motion.

The second form of image displacement is the displacement of a portion of the total image while the image of the field in general is stationary. This is produced when a restricted target is displaced laterally (that is, in the frontal plane), with the eyes stationary; one experiences the movement of an object in a stable field. This is a very common situation, as for example seeing a bird fly past a window as one is looking out at the scene.

The third pattern of retinal change occurs when the eye follows a target that is moving in the frontal plane. The image of the visual field as a whole moves, while that of the pursued target remains fixed on the retina. If one actually follows the flight of a bird as it goes by in the frontal



External conditions	Motion of image on retina	Perception of movement
Saccadic eye movements as in reading, visual target motionless	Uniform motion of all parts of overall image	No object movement perceived
Eye motionless, small target moving frontally	Motion of image of restricted target, no motion of overall image	Object motion in frontal plane, rest of world motionless
Eyes pursuing small target moving frontally	Motion of overall image with image of target fixated (pursued)	Only object motion in front plane
Head not turning, body in motion in stable visual environment as riding in train and fixating on horizion	Deformation of overall image, parts representing distant targets stable or more nearly so than closer ones	Perceiver moving in stable world, moving past near objects faster than more distant objects
Eyes motionless, target moving in third dimension	Deformation of overall image, image of restricted target growing or diminishing in size	Object moving toward or away from perceiver in stable world

Fig. 9.1. Relations between movement of external conditions, retinal images, and what is seen. (After J. J. Gibs on. *The perception of the visual world.* Boston: Houghton Mifflin, 1950.)

plane, its image remains fixed on the fovea, while the image of the scene moves across the retina.

The fourth kind of retinal change occurs when the head or head and body are moved and nothing is displaced in the external environment. The retinal image of the whole field tends to be deformed. Images of targets close by move across the retina most rapidly. The targets progressively farther and farther away move less and less. Hence, there is an internal rearrangement of elements in the target field as a whole. The impression is one of self-movement in a stable world. This is well exemplified as one gazes out the window of a moving train: the horizon is still while objects nearer and nearer move faster and faster.

In the fifth kind of retinal change nothing but a restricted target moves in the third dimension. The target image grows or shrinks in size and may change somewhat in shape. The perception is of an object moving in the third dimension while the environment stands still. This is exemplified if the bird flies either toward or away from the observer as he watches it.

The displacement of the total image or some part of it occurs in each of the five cases because there is a lawful relation between what happens on the retina and the photically relayed events outside the organism. The adult individual sees what he sees partly depending upon the changes that occur in the pattern of stimulation on the retina and partly on account of having developed a reaction pattern that is in lawful relation to the positions and motions of other items in the visual field. This reaction pattern stems not only from the motions of other items but from the motions the individual has to execute in dealing with these items.

Acceleration versus motion

The perception of motion of the body is mediated by vision, kinesthesis, and the vestibular sense. The retina is totally insensitive to forces such as acceleration acting upon or within the body, but the semicircular canals and otolith organ are very sensitive to forces such as gravity and acceleration that act upon the body. (These same mechanisms are, on the other hand, insensitive to conditions not involving force.) But only when displacement and force are linked in certain ways do they operate to produce the experience of motion. Very peculiar end results sometimes occur, depending upon how the two forms of stimulation are coupled. Take, for example, the case in which a person drives his car into an angled parking place and just after he has come to a stop another car pulls into the space alongside. A possible result for the first driver, if he restricts his visual field to glancing at the second car, is to feel as though he is in motion. A mere instant before, he supposed that he had come to a dead stop. But at the instant of viewing the second car in motion there is relative visual displacement between his car and the car alongside. This relative displacement

gives rise to perceived motion but not in an ordinary way. The experienced motion occurs without any application of force on the vestibule that is characteristic of all acceleration. The acceleration-force factor is lacking, and its absence distorts the usual sensory input to the central nervous system. The usual innervations contain vestibular and kinesthetic components. It is perhaps on account of the absence of these that the experience of visual motion of oneself is in such a case very peculiar. In fact, the experience contains a definite aspect of uneasiness. One might call the experience a twinge of sickness. The main twinge is over within a second or two, but the after-effects may last for some time. It may be said, then, that not all motion sickness is brought about by contributions from the vestibule but some may result when usual contributions are absent when they ought to occur.

A bit of the same momentary uneasiness is likely to occur when sitting in a stopped train and seeing a train on the next track begin to move. One sees his own train moving instead. But here again there is some sort of uncertainty and possibly some uneasiness. The experience carries at least a kind of ambiguity. Again, the usual sensory component is lacking. It is the kinesthetic stimulation that vibration of active motion would set up. Since one's own train is motionless, there is not the least basis for the usual muscular factor underlying the motion one sees. Lacking the jolting, vibrations, and so on, the movement is fantastically smooth and a bit "unreal." One is quickly led to look around in various directions to try to make sure whether it is his own train or the other one that is moving. The answer to the question of how one came to see visual movement in the first place lies in the structure of the visual field. The railroad car seen through the window is seen as a portion of overall stable externality, whereas one's own car is taken to be a restricted portion of the environment more-or-less identified kinetically with oneself.

Direction of flow

When the perceiver moves about in space, the visual field changes in accordance with the relation between direction of locomotion and the perceiver's direction of gaze. Obviously, the common description consists in statements regarding objects "getting nearer or farther away" or regarding "moving past" objects. A way of dealing with the matter other than the everyday one is to consider what happens to the retinal image in various cases. Essentially what happens is a shift of pattern across the retina, and J. J. Gibson (1950) calls this *flow*. Descriptions of flow tell what happens on the retina.

In Figs. 9.2 and 9.3, the directions of flow are indicated. In figure 9.2, the directions of flow are for the eye looking straight ahead as the perceiver moves forward. In figure 9.3, they are for the eye looking at right angles to

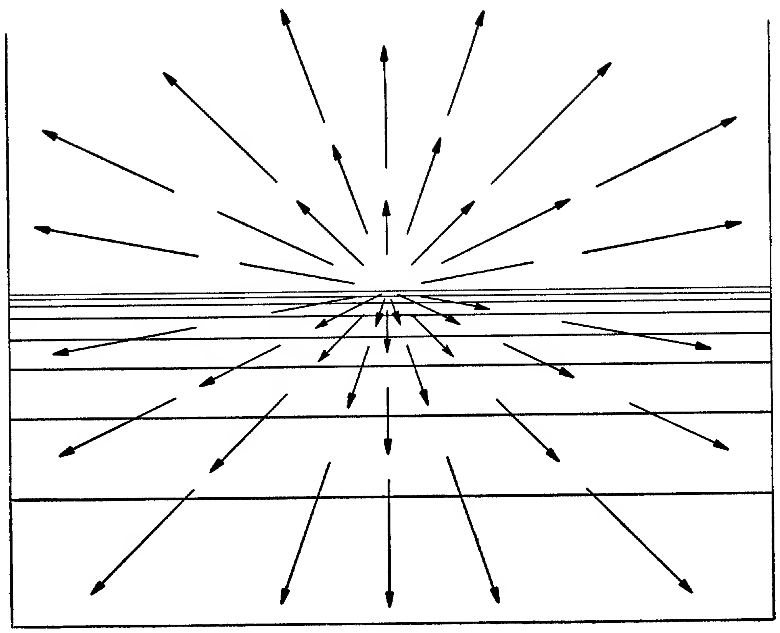


Fig. 9.2. Direction of flow of the textured field, made up of land and sky, during an observer's forward motion, particularly when off the ground as in an airplane.

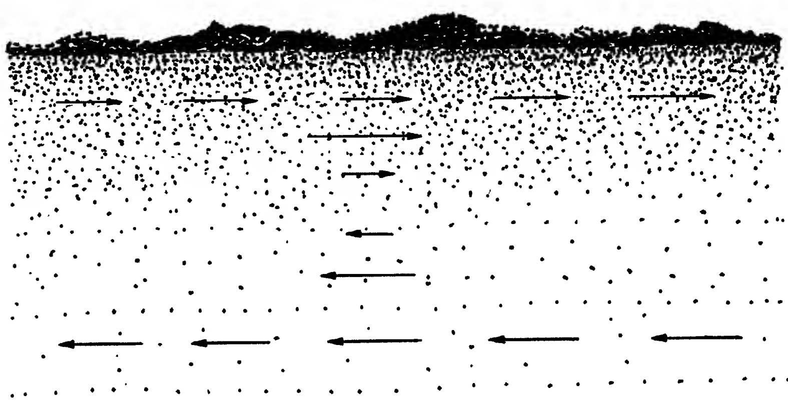


Fig. 9.3. The direction of flow of the textured field, made up of land, when the observer looks to the left and fixates a point in the field midway between the observer and the horizon, as one moves along.

the direction of motion (in this case, looking to the left). It will be noticed that in the first diagram the flow is upward for positions below the horizon

and downward for positions of the field representing sky. These directions are exactly opposite to what one might expect, but this is because the retinal image is "upside down." The rate of flow is least near the horizon and greatest near the observer. The same thing is true with regard to rate when the observer is looking at right angles to the line of his motion. The direction of flow in this case is parallel to and in the direction of motion of the perceiver.

There is still another condition that might well be mentioned and that is the sort of flow involved when one looks to the side—that is, at right angles to the direction of motion—and fixates a point on the terrain *between* himself and the horizon. This point becomes the point beyond which there is flow in the direction opposite to the perceiver's own movement and on this side of which the flow is in the direction of body movement. (The reader will be helped out of confusion if he simply visualizes the direction in which objects move past him as he moves.)

Movement of perceived objects

So far we have been describing the overall changes in the *retinal images* and the overall perceived effects during motion of the field or of the observer. We now come to consider the perceptual features of seen objects in motion.

Aubert (1886) was one of the first investigators to obtain measurements of thresholds for object motion. For a long line target in a structural field, he reported a threshold of 1 to 2 minutes of arc per second when the target itself was fixated. With a virtually unstructured field, the values given were ten times as great. Later investigators verified Aubert's results.

The threshold for movement perceived at 9° from the fixation point was about 18 minutes of arc per second. Threshold differences in rate of movement for certain targets near the fixation point turned out to be about 1 to 2 minutes per second. Graham, Baker, Hecht, and Lloyd (1948) obtained a value of 30 seconds of arc per second for the threshold difference in the rate of slow-moving targets and a value of about 100 seconds for fast-moving targets. J. F. Brown (1931) studied the relation of phenomenal (perceived) movement to rate of physical displacement in a field by using an endless broad belt upon which variously sized, shaped, and spaced targets were placed from experiment to experiment. Actually, Brown used two such setups, one as a standard and the other as a comparison field. The observer could shift his gaze from one to the other, since they were placed so that they would not both be visible at the same time.

Brown found that as the physical velocity of a moving square target is increased from zero to 200 centimeters per second, several kinds of thresholds obtained, including (1) just perceptible movement, (2) a kind of reversed movement produced when one target moves out of the field as

the succeeding target moves in, and (3) velocity at which the targets become a gray band instead of being distinct individuals. For the threshold of the first type, he found angular velocities of from 2 to 6 minutes of arc per second; the length and width of the field apparently contributed to these values. For the reversed movement (threshold 2), values of from 3° to 9° per second were found. The factors producing variation were field dimensions, target sizes, and distances between them on the moving belt. Threshold 3 was obtained at values of from 12° to 32° per second.

Apparent movement

Apparent movement is the phenomenal movement produced without target displacement. Physical factors such as intensity, position, and timing substitute for the usual displacement. Understanding how these factors operate as substitutes is the main task of studying apparent movement. Before we go into detail as to how intensity, position, and timing of stationary targets can substitute for the traverse of an image across the retina, we shall list the forms of apparent movement.

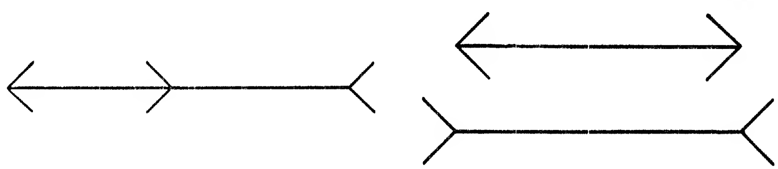
Gamma movement is the perceived radial movement outward from the fixation point when the level of illumination is suddenly raised and the movement in the opposite direction when the illumination is suddenly lowered. Raising and lowering of illumination may take various forms. For example, illumination can be raised from zero value to some finite value, or it can be changed from some material amount to some greater or lesser amount. Furthermore, the whole field may be involved homogeneously in the raising and lowering of illumination, or the specified change may involve only a restricted portion of the field, which we ordinarily call a restricted *target*. That is, gamma movement can be produced either by varying the level of the whole field or by varying only some part of it. (More details regarding gamma movement follow the discussion of beta, delta, and alpha movement.)

Beta movement is the perception of lateral movement of a single object from one place to another not greatly distant when two stationary targets are presented in succession. Beta movement is exemplified in motion pictures, in electric crossing signals (alternate flashing lights) for railroads, and in lighted borders of theater marquees. The production of beta movement is dependent upon a crucial combination of circumstances. These factors are primarily the proper distance between targets (measured in units of visual angle), the proper time interval between the presentations of the targets, and the proper target intensities. Some study has been made of these three general factors. Korte (1915), one of the investigators, formulated a loose set of "laws" that have come to be known as Korte's laws. They state that once optimal (that is, satisfactory or convincing) movement is set up, it may be maintained, even if one of the three above-stated condi-

tions is altered, *if* some compensatory alteration is made in the values of one or both of the other two conditions. Possible alterations are as follows: If distance between targets is increased, the time interval between presentations should be increased ($d \sim t$) in order to maintain good movement. If distance is increased, good movement may be maintained by increasing the intensity of the targets ($d \sim I$). If intensity is increased, the time between presentations should be decreased ($I \sim 1/t$). It is as though a space-intensity combination of brain activity had to be of a certain pattern for apparent movement to be seen. The pattern can best be held nearly constant in form by the kinds of manipulations just specified.

Delta movement is akin to beta movement except that, in addition to being a movement in the direction of the sequence in the presentation of two targets, it is finally a backward movement in the reverse direction. Delta movement is produced only when the second target is considerably more intense than the first.

Alpha movement is the apparent movement produced by presenting two parts of a geometrical "illusion" in sequence. One of the most frequently used examples of this is the presentation, one at a time, of the two parts of the Müller-Lyer figure (Fig. 9.4). In A the whole Müller-Lyer



A B

Fig. 9.4. The Müller-Lyer figure used in two parts in rapid succession to illustrate conditions for producing the alpha form of apparent movement.

figure is shown. Its right and left portions will be seen as two lines that are unequal in length but they are actually metrically equal. When the two parts are presented separately in time and in the positions indicated in B, the horizontal-line portion of the two targets will lengthen or contract depending upon which is presented first. The "wings" on the lines "flop" back and forth from one position to the other as the one target follows the other.

The forms of movement thus far mentioned all occur in the frontal plane, being either horizontal or vertical. There is also a form of movement that leaves the frontal plane, exemplified in the way the wings in the Müller-Lyer figure behave as they change their lateral positions. They pivot as they change from one lateral position to the opposite and swing out toward the observer. This behavior may be called *pivotal movement,* for it does not remain in the frontal plane.

GAMMA MOVEMENT. Since gamma movement can be taken in many respects as an example of all apparent movement, we shall discuss it more at length. Gamma movement can be used to examine the necessary retinal conditions for movement experience. Let us therefore discuss what happens on the retina when a restricted portion of the visual field is raised in illumination. Figure 9.5 shows the distribution of illumination across the

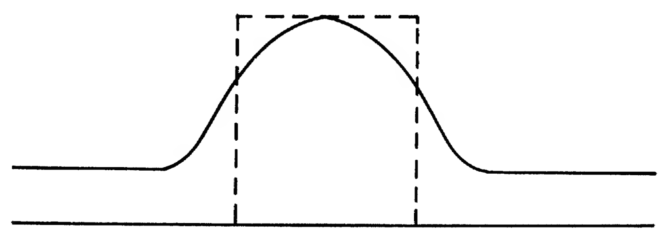


Fig. 9.5. The pattern of distribution of photic radiation across the retina is tapered and widespread (curve) rather than abrupt and restricted (broken-line).

retina when a target of restricted angular subtense is projected on it. The broken-line rectangle represents the distribution of the radiation on the retina as it would be were there no entoptic stray light and were the target mathematically sharply imaged. In contrast to this, the target supplies illumination outside the image as well as in it. (This was discussed in Chapter Six.) The intensity of the illumination of the retina is tapered from the center of the image to a considerable distance outward, and then is rather uniformly distributed from there out to the boundaries of the retina.

It is a general principle in neurophysiology that tissue responds in terms of strength of the impingement upon it. The more energetic the impingement, the sooner the measurable response begins. Tissue less strongly impinged upon responds only after a greater interval. The interval between the beginning of impingement and the beginning of response is called the latent period. So, it may be said that the stronger the stimulation is, the shorter the latency will be. As this rule applies here, it could mean that the part of the eye on which the image is projected responds first. Other parts would respond also but only after greater and greater delay depending upon the distance from the stimulated area. In other words, the receptors under the image would respond before those radial to it. The response of the eye would be in the form of a spatial sequence with the center of the retina responding first and then the portions successively farther from it. That such a result is a temporal sequence would be expected to give rise to the experience of movement. Within limits, such a succession is quite like the succession produced by the traverse of an image of a moving target.

Although the description just given applies to the use of a restricted

target, succession in activity in adjacent receptors in the retina can be produced by a uniform illumination over the whole retina. That such a target can produce gamma movement is to be interpreted as meaning that the actual receptors do not all fire off equally rapidly. That is, the rods and cones possibly do not possess the same latency or the central and peripheral parts of the retina may differ in latency on account of the way the elements are connected neurally. Possibly both factors are involved, since we know that the neural hookup in the retina for the more peripheral receptors is different from that of the more nearly foveal receptors.

It would seem, then, that even with uniform retinal illumination the more central portions of the retina react first. If this is the case, we would expect a temporal succession just as we expected a succession on the basis of relative intensity of stimulation. One step in checking on this assumption would be to see whether, on the basis of relative intensity, one could *reverse* the direction of gamma movement.

Bartley (1936a) was successful in showing that gamma movement can be reversed in direction. His target covered a large portion of the visual field: It was a large opal-glass disk over which a number of layers of tissue-paper were laid. All layers covered the center of the disk, whereas fewer and fewer layers were involved farther and farther out. When the disk was illuminated from behind, less radiation passed through central sections than through the peripheral ones. The retina therefore received more radiation toward its periphery than on portions toward the center. With the sudden onset of such a pattern of illumination, gamma movement was produced, but it originated at the periphery and moved toward the center of the visual field rather than in the usual way, outward from the center. Of course, at the termination of the stimulus, the movement spread radially outward—the direction opposite to the usual one.

In another experiment Bartley (1936a) used disk targets of varying degrees of angular subtense to check upon the then fairly common idea that gamma movement is simply a perceptual aspect of the "emergence figure upon ground." Many experimenters of the day had been using targets of small subtense, and it had been found that the edge of the seen object does expand radially as the object emerges into view. It was taken from this that gamma movement of the object border is a function of its phenomenal emergence. Bartley found that when targets of larger angular subtense were used, the gamma movement occurred within the object and the border did not expand radially as it emerged (Fig. 9.6). He drew the conclusion that gamma movement is not a secondary function of the emergence of figure upon ground but rather of the spatio-temporal distribution of stimulation of the receptor population. Once the images of target borders are a certain distance out toward the periphery of the retina, the intensity and sensitivity tapers are more gradual and movement is trivial or absent.

One of the arguments of the proponents of a psychological or central

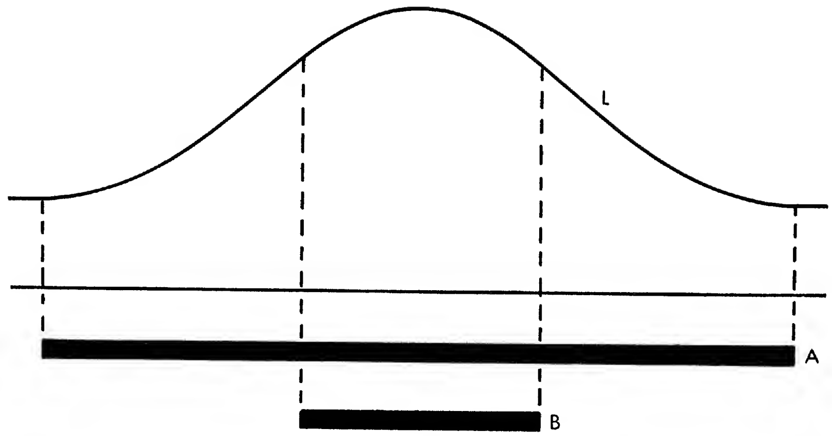


Fig. 9.6. Spatial relation of possible gradient of sensitivity across the retina to targets of various angular subtenses such as A and B. Portions of the gradient, L, that are steep function toward producing gamma movement. If the retinal image lies within this gradient, apparent movement will occur both within and outside the seen figure. If the border of the image lies radially to the steep gradient, the movement will lie well within the seen figure.

theory of the origin of gamma movement is that retinal factors are secondary because gamma movement can be produced just as well by a "black" target on a "light" ground as by a "light" target on a "dark" ground. The argument is that, by using a "black" target, no intensity or only a negligible one is employed in the target and that the rules applying to intensive targets do not hold. It can be shown that the rule of physiology used to explain movement by reason of differences in latency dependent upon relative amounts of stimulation holds as well for "dark" as for "light" targets. A withdrawal of radiation in the region of target projection on the retina is greater than for other regions. This withdrawal evokes an off-response in the retina, just as onset of stimulation evokes an on-response. It does not matter whether the object emerges as a black one or a light one; the proper succession of receptor discharge is set up. This and other retinal distributions are shown in Fig. 9.7.

MOVEMENT IN THE THIRD DIMENSION. In studying gamma movement Newman (1934) found that, under slow rates of reduction or increase of retinal illumination, movement in the third dimension could be produced. This slow rate of transition reduced to the vanishing point the kind of phenomenal movement called gamma movement and produced instead what he called depth movement. Gamma disappeared at about 300 milliseconds and depth movement began with 200-millisecond transitions.

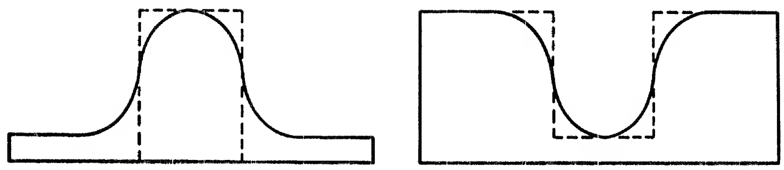


Fig. 9.7. Illumination of the retina is gradient-wise regardless of whether the target is more or less luminous than its surrounds.

More recently, Bartley and Miller (1954), using a Harvard tachistoscope,[5] studied depth movement by varying other factors. They called this movement *adab* movement, since *ad* and *ab* are prefixes meaning toward and away from. A target of a given size was replaced by another one within 0.01 second delay. In some experiments the second target was less intense but of the same size as the first, and in other experiments the second target was of the same intensity but smaller in size. The timing arrangement permitted only the variation of the duration of the second target. At its termination the first target was re-presented. The target N (a square) was viewed at a distance of 41 centimeters. The size of N was 2.6 centimeters. The other targets A, B, C (also squares) were 1.3, 1.9, and 2.27 centimeters. When the second target was the same size as N, it was called D.

Adab movement was dependent upon the intensity of the second target in relation to the first. In nearly all the conditions eliciting *adab* movement, the weaker the second target, the longer its exposure had to be. These durations ranged from 75 to 300 milliseconds for one observer and from 100 to 250 for the other.

The next factor was the relation of the size of the second target to the size of N. There was a tendency for the larger targets to require longer exposures to produce *adab* movement. The role played by target size was somewhat complicated, since it involved two factors, a variation in photic flux as size was varied and a shift in retinal image borders. Whereas the first factor would tend to elicit a quicker emergence of the second square, the second factor would operate in the opposite direction, as indicated by the work of earlier investigators who found that contour processes in the retina may work against each other when parallel.

A number of other findings too numerous and complicated to detail

[5] A Harvard tachistoscope is a form of the old Dodge tachistoscope. It is a device in which alleys can be illuminated in sequence, thereby exposing a series of two or more targets, depending upon the number of alleys. In the Harvard tachistoscope the two alleys are placed at right angles to each other and the illumination from the targets falls on a half-silvered mirror that acts as a mirror for one alley and as a window for the other, so that the ultimate direction of photic flux in both cases is the same and reaches the eye or eyes as if the second target actually replaced the first one in position. A timing device for the illumination determines the duration for each target, and in some cases it determines the length of interval between exposures.

here were obtained relating to the emergence of the border of the second target and the instability of the border of the first. The investigation was a quantitative demonstration that *adab* movement can be produced in the manner described.

THE PULFRICH PHENOMENON. Pulfrich (1922) described a visual phenomenon in which the seen path of a moving target was different from what would ordinarily be expected. The phenomenon itself was not important, but it provided for experimental manipulation and a further insight into the mechanism of space perception.

The phenomenon was produced by observing a pendulum bob with fixation on a point just below the midpart of its excursion. The bob, as any pendulum bob, appears to move in a plane. If however some sort of a filter is placed in front of one eye to reduce the intensity of the target illumination reaching it, the pendulum will no longer appear to move in a plane: Its excursion will move in a somewhat elliptical path. As viewed from above, the perceived rotation will be clockwise if the filter is in front of the observer's left eye, counterclockwise if in front of the right eye (Fig. 9.8).

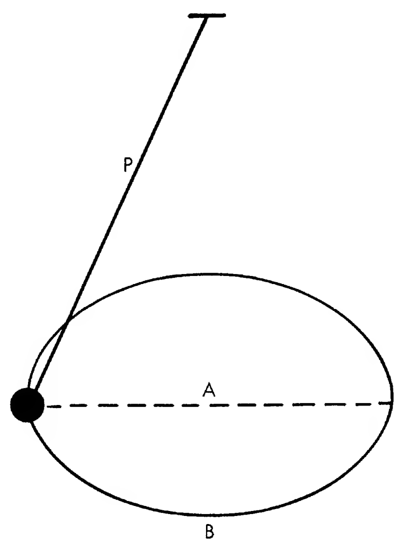


Fig. 9.8. Actual and apparent paths of a pendulum under conditions producing the Pulfrich phenomenon. The pendulum P swings back and forth in path A, but when a filter is placed in front of one eye, reducing the luminosity of the target (pendulum and background) for that eye, the pendulum no longer seems to traverse a plane path. It now seems to traverse an elliptical or rotational path B. Various experimental conditions can be used to manipulate the magnitude of this effect, called the Pulfrich phenomenon.

If the filter reduces the intensity of the input too greatly, the rotational path is obliterated and the bob again moves in a plane.

An associate of Pulfrich explained the phenomenon on the basis of reduced stimulation in the eye covered by the filter, increasing the latent time of response in that eye. Whereas corresponding points in the two retinas simultaneously stimulated would react together, the reaction of the points in the filtered eye suffered a delay. This caused a shift in the apparent position of the bob.

Lit (1949) and his associates began to study the phenomenon further. Lit and Hyman (1951) introduced a methodological improvement whereby the seen target was no longer a pendulum bob but rather a dark rod projecting into a horizontal luminous rectangular opening (or field). The rod moved back and forth along the opening, replacing the bob in the original setup. A similar dark rod projected upward into the rectangular field (Fig. 9.9) and could be moved in the third dimension (away from the

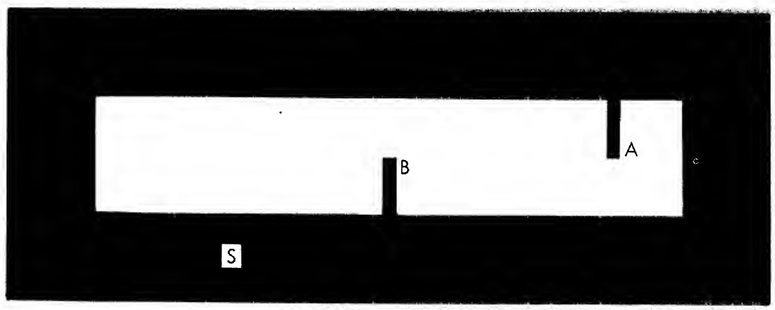


Fig. 9.9. Lit and co-workers substituted a rod moving back and forth in a plane just behind the opening of the reduction screen S for the Pulfrich pendulum. A second rod B is provided for determining the extent of the third dimensional (elliptical) effect. B can be adjusted in the third dimension so that the oscillating rod A seems to pass directly over it when at the midpoint in its excursion. The calibrated position of B then indicates the magnitude of the Pulfrich effect. (A. Lit & A. Hyman. The magnitude of the Pulfrich stereophenomenon as a function of distance of observation. *Amer. J. Optom., Arch. Amer. Acad. Optom.*, 1951 (No. 122), Fig. 2A.)

observer) and set so as to appear directly under the oscillating rod at its midexcursion, thus providing a measure of the apparent displacement of the oscillating rod when the observer wore the filter over one eye.

They found that magnitude of the linear velocity of the rod varied with the observation distance while its angular velocity remained the same for all viewing distances. The results were taken to be consistent with the theory and geometric analysis of the phenomenon.

Lit (1959) varied the level of illumination over a range of 5 logarithmic units and found the precision of depth discrimination to increase twenty-fold. Three different fixations were used and produced different degrees of precision of depth discrimination, except at the very lightest levels of illumination.

Lit (1960) showed that the rod varied in its apparent displacement from the plane of oscillation in accord with oscillation velocity. This result was also taken to be in good agreement with the theory of the Pulfrich phenomenon.

Perception of motion of revolving plane targets

One of the most frequently studied targets of the sort referred to here is the trapezoidal window. The Ames trapezoidal window (Ames, 1951) is a plane piece of metal or other material in the form of a trapezoid (Fig. 9.10). Upon it is painted the mullions of a window, and thus it has

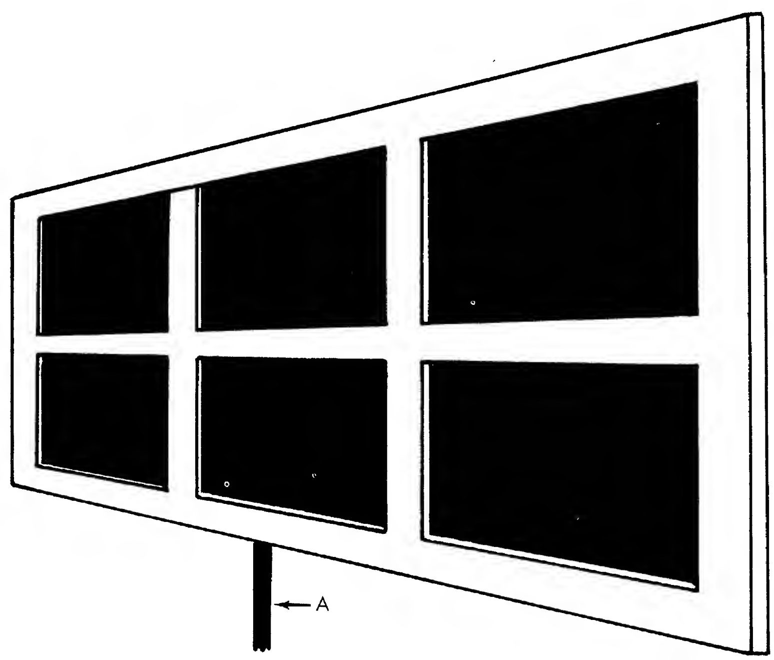


Fig. 9.10. The Ames trapezoidal window, consisting simply of a plane sheet of material in the form of a trapezoid with the features of an ordinary window painted on it. This "window" is rotated on a post A. Plain trapezoids are also used to study some of the same conditions produced by the simulated window.

the appearance of a window viewed obliquely. It is pivoted on a vertical axis at about its center and can be rotated by a motor and viewed while in motion. The rate of rotation can, of course, be manipulated and used as one of the variables.

While the most common form of the trapezoid used is the one with the window painted on it, the problem of the perceptual results from rotating a plane target can be and has been studied by a plain trapezoid. One of the main things seen as the trapezoid rotates through 360° is that instead of the appearance of a complete rotation, the trapezoid seems to oscillate back and forth.

Day and Power (1965) studied rotary motion in depth in which the perceptual effect was oscillation instead of complete rotation. They took a more general view of the matter and did not confine themselves to the trapezoidal window, or even to a plane trapezoid, but also studied unstructured forms, including an ellipse and three different irregular shapes. They also included a rectangular window. They found that oscillation was seen with all the forms used and that the perspective effects in the trapezoidal window do not increase the reversal tendency. The authors reported that their experiments failed to confirm the assumption that misjudgments of orientation are causal. They said that apparent orientation is a consequence of rather than a causal condition for the perceived oscillation.

The outlook of Day and Power on the reversal (or oscillation) effects included the other well-known reversals found in viewing the Necker cube and the Schroeder staircase as well as other motionless targets. The fact that these figures produce their effects when the targets are three-dimensional as well as when only two-dimensional is reason for their inclusion with the moving targets. Their theory of the reversal effects includes the idea that when there is identity of projections in retinal images for two or more motionless orientations in depth, or two or more directions of movement in the third dimension, reversals will be seen when "cues" to true orientation or movement are not present. They coined the term "projective identity" for the condition underlying the perceptual reversal.

Freeman and Pasnak (1968) studied the reversals in a plain trapezoid in which the linear perspective and the horizontal visual angle subtended by the trapezoid were varied. The amount of angular traverse in the oscillations was measured by a comparison target consisting of a rectangle mounted on a vertical axis and positionable so as to coincide with the apparent position of the trapezoid when at the ends of its excursion. It was found that the planes of apparent reversal were determined both by the amount of linear perspective (the ratio of size of the small end to the large end of the trapezoid) and the horizontal visual angular subtense of the rotating target. Which of the two factors dominated was dependent upon the required judgmental task (instructions and means for indicating response).

Allport and Pettigrew (1957) used the Ames trapezoidal window to test primitive subjects, because perception is partly a product of learning and partly a product of the anatomy and native organization of the species. In the past, theories of perception have been of two opposing sorts; some have been *nativistic* and some have been *empiricistic*. The trapezoidal window setup was thought to be a good test arrangement to see whether primitive peoples might differ essentially from nonprimitive people in how they reacted to the window.

The authors used eighty observers in four different groups of twenty each. Group A involved urban European boys, Group B urban African boys, Group C Polela rural African boys, and Group D Nongoma rural African boys. The African observers were between the ages of 10 and 14 years as nearly as could be ascertained. Both binocular and monocular viewing were used at two different viewing distances, making in all four different conditions.

Pooling the results of all four conditions there was a very definite tendency for the urban boys to report the "illusion" more often than the rural boys. Under Condition I (binocular at 10 feet) the difference was most marked. Under the second condition (monocular at 10 feet) there was a significant trend toward difference. Under the third condition (binocular at 20 feet) there was a slight trend for the urban to report illusion more often. And, under the last condition (monocular at 20 feet), virtually no difference was manifested between the rural and urban boys.

The authors concluded that the character of the motion perceived in viewing the rotating trapezoidal window is governed under optimal conditions by inherent determinants or by unconscious utilization of past experience or both. They were not able to decide which.

Neurophysiological experiments

Certain neurophysiological experiments were performed by Bartley (1936b) that were quite parallel to many of the standard perceptual (psychophysical) studies on apparent visual movement. Using an optic setup that would sequentially stimulate two parts of the retina in the rabbit, he recorded from various areas in the cortex. Naturally, he was not able to deal with the rabbit's sensory response, but he was interested in determining how various portions of the animal's optic cortex reacted as the timing of the two photic inputs was varied.

He showed that certain cortical points could be found in which the two retinal inputs facilitated each other when applied simultaneously but when they were separated slightly in time they would nearly eliminate the cortical record. When stimulus A later failed to elicit a response of its own, it still augmented the response when A and B were both delivered and reduced the size of B when out of phase with it.

Among the conclusions drawn from the results as a total was that the interaction between cortical points was more widespread than that between retinal points. This investigation was only a pioneering one, but it did demonstrate the feasibility of making an extensive study of the neural conditions for apparent movement. Such a study would first involve the training of animals to respond differentially to targets, so that when seen as two stationary targets the response would be one thing, and when seen as a single moving target the response would be something else. Implanted electrodes would be necessary if the overt response and the neural records were to be taken simultaneously.

TACTUAL MOVEMENT

We are now ready to deal with apparent tactual movement. Whereas there is no doubt that the visual modality provides for both apparent and real movement by way of its own mechanisms, there is some doubt about certain features of apparent movement that are called tactual.

Tactile stimuli may traverse the skin surface and be felt as something moving. Of this there is no doubt. The experiences of tactile movement aroused by successions of stationary stimuli have also been reported. Burtt (1917b) reported on results that he labeled tactual illusions of movement. This was not long after the work of Wertheimer (1912) on visual apparent movement became well known. Following the lead of early workers, who manipulated the stimulus conditions in a fairly lawful manner, Burtt manipulated the same essential conditions in the study of movement experiences elicited by stationary tactual stimuli. The factors manipulated were temporal intervals between contacts with the skin, exposure times (that is, durations of contact), and the spatial separations between contacts. The temporal intervals he used were 15, 21, and 40 milliseconds. The durations of contact were multiples of the interval times.

He found that, in general, the greater the distance was between contacts, the greater was the time interval needed to produce apparent movement. He found also that the greater the intensity of contacts was, less time was needed to obtain or maintain movement. He also found that the greater the distance between contacts was, the greater their intensities needed to be for movement. Furthermore, when the intensity of the second contact was made greater than that of the first, movement in the reverse direction was sometimes produced. These results followed Korte's laws for visual apparent movement.

Another set of generalizations regarding his findings was made in the following fashion. Shortening the exposure time (duration) gives the impression of simultaneity or fusion of the two contacts, other things being equal. On the other hand, increasing the exposure time tends to produce the experience of movement. Still greater durations of contact tend to give

the impression of discrete succession. Obviously, these manipulations work in the ways specified only up to a certain point.

Hulin (1935) varied the separations of his two stimuli from simultaneity up to 300 milliseconds between the ending of the first contact and the beginning of the second. The spatial separations varied from 5 to 150 millimeters. In the many thousands of trials used, about 30 percent yielded some form of apparent movement. The forms of movement were classified into full, end, inner, and bow movement. Taken together these were called optimal movement. In general, the most cases of movement were obtained when the two stimuli overlapped by about 75 milliseconds. Full movement showed a decided peak with an overlap of 75 milliseconds. The other types varied somewhat indefinitely. Hulin was unable to verify Korte's law for the relation between space and time.

Hulin deduced that there were four principal factors at work to produce the experience reported: pressure irradiation, perseveration and associated factors, visual imagery, and kinesthesis. He pointed out that Wundt, many decades earlier, had said that the idea of locality on the skin stemmed usually from visual associations. This is to say, he attributed great potency to visual imagery in producing tactual space effects. Another earlier investigator asserted that persons with good visual imagery did better in tactual localization than those with poor visual imagery.

There is probably nothing about the strictly quantitative features of the results obtained by these and other investigators that can be used to distinguish whether the movement experience is actually tactual or a product of visual imagery. Various qualitative features of the reports that testify to visual imagery are our best evidences.

Bow movement

One of the kinds of movement reported upon was bow movement. This is the experience of movement from one place on the skin to another, but instead of the path of the movement being confined to the skin or body, it bows into the air above the skin surface. DeHardt (1961) studied apparent tactual movement, including bow movement. The movement perceived as progressing on the skin she called on-skin movement. The movement perceived (whether actually "tactual" or not) she called off-skin movement; this was the kind others have called bow movement. She found that the time interval (TI) to produce either on-skin or off-skin movement did not have to be inversely related to contact duration (D) as was expected. She found that the frequency of obtaining on-skin movement was inversely related to TI. The completeness of on-skin movement was also inversely related to TI. Both quantity and quality of on-skin movement were greatly dependent upon the pliability of the skin tissue. With her longer time intervals, the frequency of off-skin movement was directly re-

lated to both time interval and spatial separation between contacts. She also concluded that the experience of off-skin movement is dependent upon considerable "time" and "room" and that this movement is the result of exciting appropriate visual images.

Many astute observers who have had the experiences of bow movement have come to the sure realization that what they were reporting upon in bow movement was visualized movement elicited by tactual stimulation. They tended to call it "illusory." Bow movement from tactual stimulation seems to be another case of associative imagery, which we have already described in other connections.

Another difference between bow movement and strictly tactual apparent movement is that bow movement contains none of the true tactual feeling quality, whereas true tactual apparent movement actually *feels* as though something is dragged across the skin.

The two forms of movement elicited tatcually bear upon what we have already said about the tactual modality not being spatial in the sense that it pertains to space away from the body. The distinction seems to be borne out in the results we have been discussing. They point toward the conclusion that that which is really tactual is body-confined and that not all experiences elicited by tactual stimuli need be tactual in the strict sense. However, some of them are so intimately connected with the tactual that many observers fail to be aware of the distinction just made.

Active and passive tactile activity

The tactile sense is involved in two ways, one in appreciating that which is moved across the skin and one in appreciating contacting-surfaces, points, and so on when the individual moves across them. This second appreciation is usually involved in what is called *active* movement. That is, it is the result of movement supplied by the subject's own muscles. There are times, of course, when the hand or some other part of the body is carried or slid across a surface by some outside force. Such movement is *passive*. There are two forms of passive movement, one when the body member is slid across a surface and the other when the surface is slid across the body member.

J. J. Gibson (1962) has dealt with the differences between active and passive movements in discussing active and passive touch: touching and being touched. This distinction would be of no significance for us were it not for the differences in the experiences produced in the two cases. Gibson calls the two cases touching and contact. Of course, we are here going beyond mere touch and contact to moving touch and moving contact. One factor touching involves that contact does not is kinesthesis, and at times it involves the vestibular sense when contact does not. Gibson points out, very aptly, that sensory activity is formally studied as though the organism

were engaged in asking "Which sense modality is being activated?" whereas, in fact, it is generally acting as if to answer the question "What object or quality is being dealt with?" and, beyond this, "Is it harmful or beneficial?" Little work has been done in this area; hence we have no clear-cut formal experiments to cite. Nevertheless, its consideration must be met for a more penetrating understanding of perception and its role in general behavior.

AUDITORY MOVEMENT

The question of whether the experience of movement elicited by stationary tactual stimuli is actually tactual is the same sort of question to ask in regard to the movement experiences produced by stationary auditory stimuli. It is taken for granted that acoustic sources undergoing physical displacement in space produce genuine auditory movement experiences. We need to consider what happens when using stationary stimuli.

Mathieson (1931) studied phenomenal movement produced by acoustic stimulation producing clicks whose intervals were controlled. She also controlled illumination. The object of the investigation was to determine the compulsory conditions for auditory movement experience after the manner involved in visual experiments. No compulsory conditions were found. With the conditions used, movement experiences were obtained in only 4 percent of the 6000 trials involved. Experiences called movement experiences included all the cases in which some sort of "filling in" took place between the first and second experiences produced by the pair of stimuli. The movement experiences were accomplished by visualization, according to Mathieson. The range of intervals within which movements were found did not tally closely with phenomenal reduction of distance. Conditions of dichotic hearing seemed the most favorable for filling in, or movement. The failure to obtain good movement would seem to be due to the use of click-producing stimuli rather than some less abrupt and quickly terminating sound sources.

Burtt (1917a) studied what he called auditory illusions of movement. He found a rather definite relation between the duration of stimulation and the interval between exposures needed for the movement experience. If the intensity of the second stimulus was greater than that of the first, the apparent movement was often exeprienced in the reverse direction. The longer the exposure was, the shorter was the optimal interval for producing movement. A second acoustic source may produce an abruption or added impulse before the first is completed, and the continuity of the two produces the experience of movement.

CONCLUSIONS

It would seem that the production of movement experiences by visual stimuli is quite common in both the tactual and the auditory realms; their

production is fairly difficult with stationary stimuli. The conditions are quite crucial, and in certain investigations the experimenters have not seemed to hit upon the most favorable conditions.

Additional factors in determining whether movement is reported in experiments involving stationary stimuli are the bias and training of the subjects and the understandings of the experimenters. While these factors do not pertain alone to the study of apparent tactual and auditory movement, they certainly enter in quite crucially.

It seems plausible to conclude that many of the movement experiences induced by stationary tactual stimulation were actually visual experiences, that is, results mediated by visual imagery. Some, of course, were true tactual experiences, and we believe they can be differentiated qualitatively from the former kind.

In audition, the movement experiences seem to be mediated by visual imagery. This is particularly true with stationary stimuli, but it seems to be true also when physical displacement of the acoustic source is involved. That is, hearing is spatial only by reason of visuo-imaginal participation that forms the matrix within which sound is heard.

SUMMARY

This chapter on the perception of movement began with a discussion of the various possible forms of perceived movement, including psychology's conventional distinction between real and apparent movement and the author's criticism of the distinction.

The first grand division of the chapter presented work in visually perceived movement—the role of kinesthesis and the vestibular sense in the visual perception of movement and the various forms of apparent visual movement. It also included studies on the perceived effect produced by revolving rectangles and trapezoids, with the Ames trapezoidal window as one example.

The second division dealt with tactually perceived movement. This included the sensory distinctions between active and passive movement and studies on tactual apparent movement, including a form of movement called bow movement.

The third section discussed auditory movement, including apparent auditory movement.

4

TEN

Hearing

In this section we begin to deal with a different form of energy as a stimulus: It is mechanical rather than radiational. Nevertheless, some of the same principles and concepts pertain to it as pertained to the visual stimulus. For example, both forms of energy are reflected from surfaces and are thus manipulatable after they leave the sources that generate them. Both types of energy can be focused, and one can talk of sound shadows as well as visual shadows.

This vibratory energy carries information concerning external events. It indicates: (1) their nature, thus permitting identification; (2) their direction; and (3) their distance. The hearing mechanism functions also in registering vibrations made by the individual himself, particularly in vocalization. The hearing of one's own voice, for example, permits the control of temporal patterns of acoustic output. Gibson (1966) calls special attention to the fact that this "vocal-auditory loop" is well fitted as a vehicle for social interaction between organisms.

As we begin to discuss the sense of hearing, there are a number of terms that need to be defined and distinguished from each other. We shall use *audition* as a synonym of hearing; it is a generic term covering all that pertains to hearing. *Acoustics* pertains to the transmission of vibrations in the frequency range resulting in hearing. Thus the first term pertains to response and the second to the impingement or the stimulus for hearing. *Sound* is what is heard. It is not the appropriate name to give the vibratory energy producing sensation; it keeps things clearer to speak of the *acoustic stimulus* or acoustic impingement for this. It is unfortunate that there is no customary single word for the purpose. *Pitch* is a response term pertaining to a quality of the sound heard, which is designated as high or low. Fre-

quency is the stimulus feature most closely related to pitch. *Loudness* is also a response term. Loudness is most closely related to the energy content of the impingement; thus one can say a sound is loud and that the acoustic input is intense.

THE ACOUSTIC STIMULUS

Within certain frequency limits, any vibratory motion that can be made to impinge on the auditory mechanism is able to evoke the experience of sound. Stimulation most usually occurs by way of acoustic waves in air, but at other times by way of vibrations in water or in the bones of the head. Acoustic sources intermittently compress and allow for expansion of the air as they vibrate and thus set up the traveling waves which reach the ear.

Most vibration is complex. That is, it is not confined to a single frequency of compression-expansion alternation but is rather a mixture of frequencies. All such patterns can, however, be analyzed into a group of simple frequencies, each with its own amplitude. Such a procedure is known as a Fourier analysis and can be accomplished by special devices in use today. All the component waves that result from this analysis are sine waves. The complex wave pattern shown in Fig. 10.1 is analyzable into the three sine waves indicated.

Békésy (1959) pointed out that there are at least six ways that hearing can be produced: (1) airborne vibrations, (2) mechanical vibrations applied to the skull (bone conduction), (3) electrical stimulation of the ear, (4) electrical stimulation of the acoustic nerve, (5) electrical stimulation of the auditory cortex, and (6) without any intentional stimulation whatsoever. The latter case is exemplified in *tinnitus*, the temporary or chronic "ringing" in the ears.

THE EAR

The ear can be said to have three major components, the external ear or *pinna*, the inner ear, and the middle ear, a canal reaching to the inner ear. It is the inner ear as a sensitive mechanism that we are mainly interested in.

The middle ear ends at the tympanic membrane or ear drum (Fig. 10.2). To the inner surface of this, one of the three tiny bones (the ossicles) is attached. To this bone is attached a second, which in turn is articulated with the third, the *stapes*.

The overall structure of the auditory part of the inner ear is called the cochlea, a coiled tube of 2¾ turns. The vibration of the ear drum is relayed to the oval window at the base or beginning end of the cochlea. For our present purposes, we need not go into great detail in describing the cochlea.

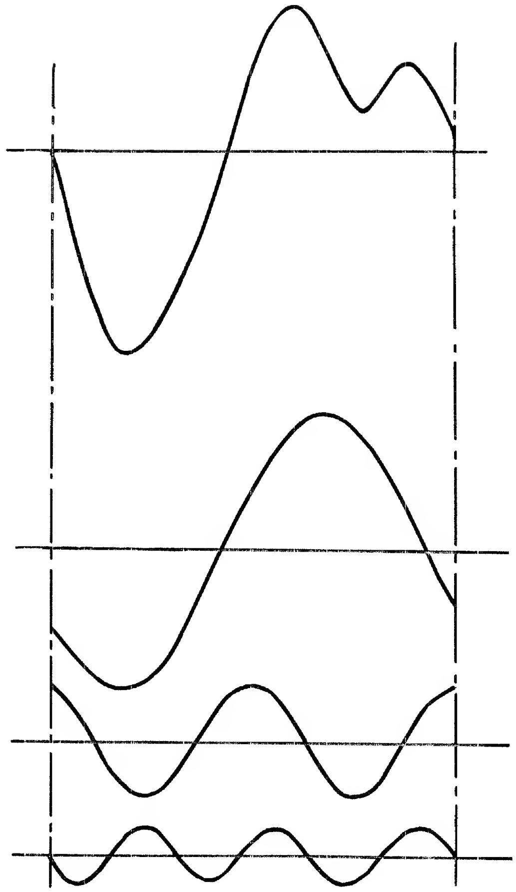


Fig. 10.1. A complex wave at the top, analyzed into its sine wave components as the three lower waves.

It has been ably done in textbooks on the anatomy and the neurophysiology of the ear. The structure of the cochlea can be summarized as follows. To aid us in visualizing the ear let us imagine that the cochlear helix is uncoiled so that we have a straight tube. This tube is partitioned into three longitudinal compartments, each of which is filled with fluid. Two of these are of major importance in our description.

One compartment, The *scala vestibuli,* is in effect continuous with the second compartment, the *scala tympani* (Fig. 10.2), by reason of the fact that the partition does not reach the whole length of the cochlea but ends in the opening called the helicotremia. Mechanical effects imparted to the fluid in the scala vestibuli are transmitted, of course, to its walls and ulti-

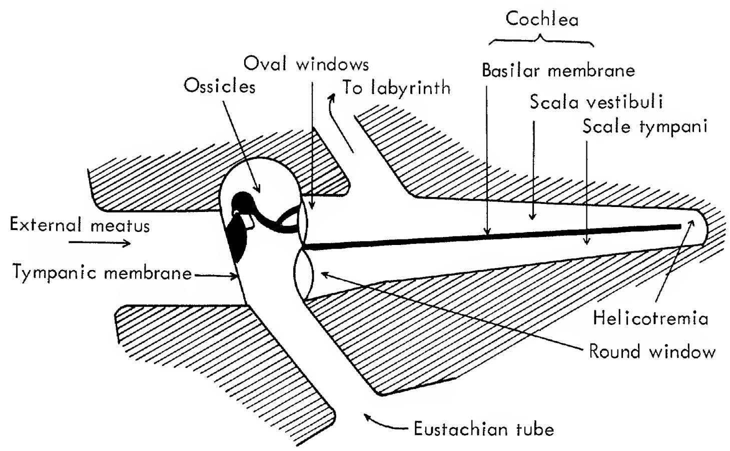


Fig. 10.2. The inner ear. The components significant for our purposes are labeled.

mately clear around to the base end of the scala tympani. The partition between the two compartments involves several layers, one of which is the *basilar membrane* (Fig. 10.3).

Along the basilar membrane there are four rows of external or outer hair cells and a single row of internal hair cells. These initiate the

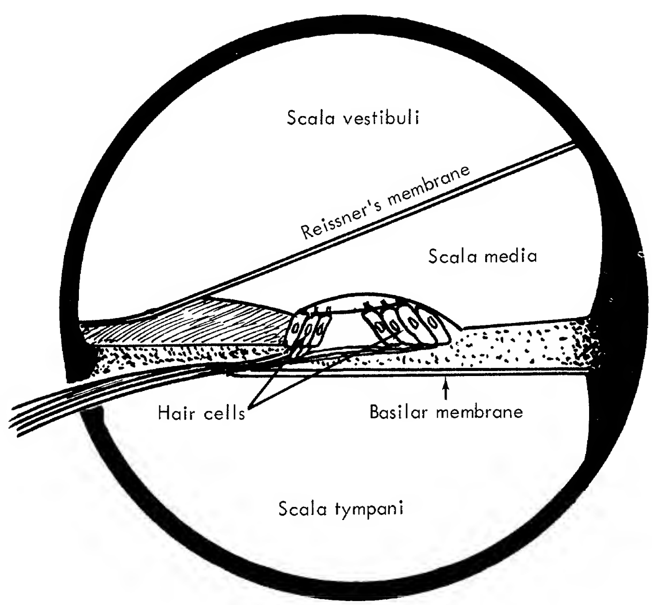


Fig. 10.3. Cross-section of the cochlea.

physiological response that feeds into the fibers of the auditory nerve attached to them. The hair cells and the fibers of the auditory nerve constitute the neural portion of the ear. The mechanical disturbance of the hair cells constitutes the immediate event that sets up the process ending in impulses being propagated along the auditory nerve.

AUDITORY SCALING

The decibel

For measurement of the energy of the acoustic stimulus, there is a very convenient and appropriate unit called the decibel. In biological work, it has scarcely been used at all except for quantification of the auditory stimulus, although it is applicable for other measurements such as photic radiation.

The decibel is proportional to the general magnitude dealt with. This characteristic is quite appropriate, since sensory reactions are themselves proportional to the energy levels involved. A decibel is specified as

$$\text{db} = 10 \frac{\log E_2}{\log E_1}$$

when E_1 is the threshold energy for activating the hearing modality and E_2 is the energy in use at the time. Both measures are in absolute energy units. The use of the decibel provides for plotting on the same graph amounts of energy near threshold and huge amounts near the upper end of the usable range. The number of decibels generally considered to lie within the full range of stimuli for hearing is 120. At this upper limit are such acoustic sources as airplane motors and thunder. The acoustic energies generated in a boiler shop are of about 100 decibels. Those of a busy street in traffic are at about 70 decibels. Conversation is rated at 60, the typical office at 40, and a whisper is probably 15 decibels. These figures sound very unrealistic, for one tries to relate them in a simple fashion to the loudnesses of the various situations specified. The decibel does not refer at all to loudness but rather to the energy involved in the pressure vibrations set up.

The sone

In order to have a unit that pertains to loudness, Stevens (1936) applied ratio scaling in obtaining the relation between experienced loudness of a tone and the energy that produced it. He had his subjects adjust a tonal source so that they would hear a tone one-half as loud as the standard tone. By using standard stimuli of various energy contents, the whole scale of energy inputs was explored. To begin with, however, a unit of loudness had to be chosen. It was recognized that all sources of the same energy

content do not sound equally loud. Some of the higher frequencies sound louder for the same energy involvement. Therefore, a frequency had to be selected for use as a standard, and the frequency chosen was 1000 cycles per second. With this, a given energy content had also to be chosen. It was decided that a source with an energy of 40 decibels would be appropriate—that is, would be a conveniently sized unit. Thus a *sone* is a unit of loudness and is the loudness of a tone produced by a source of 1000 cycles per second and an energy content of 40 decibels. The sone is simply the loudness heard under such conditions. Two sones are the loudness of a sound twice as loud as one sone. By fractionation, the subject step by step provided data for a loudness scale in which the numbers involved have the very same properties as those in our cardinal number scale in arithmetic. The curves in Fig. 10.4 show the relation of sones to decibels. It will be seen that sones are plotted in logarithmic terms. Decibels are already logarithmic units.

The family of sone curves, one curve for a given frequency, shows that

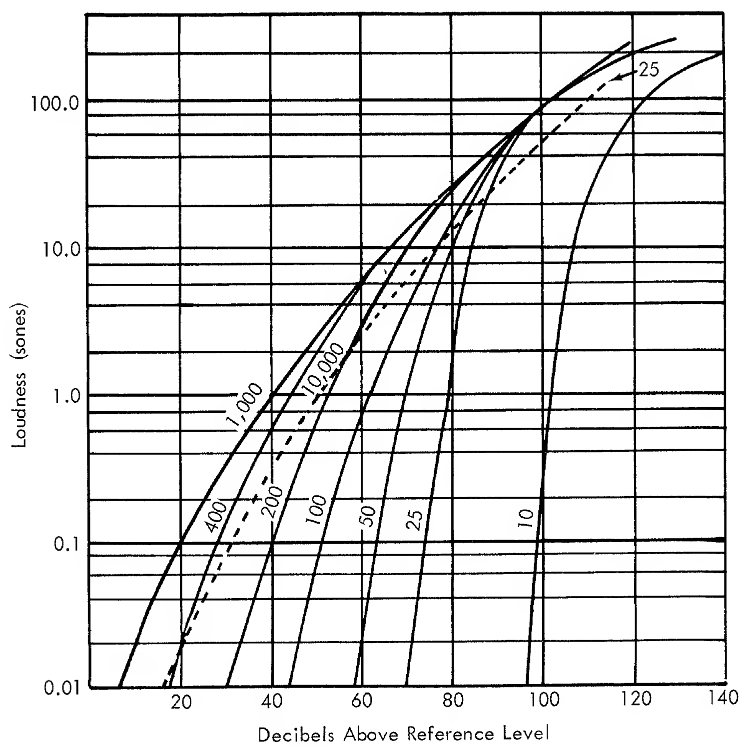


Fig. 10.4. Curves showing the relation between loudness in sones and the acoustic energy input in decibels. Each curve is for a different vibration frequency. (S. S. Stevens & H. Davis. *Hearing: Its psychology and physiology*. New York: Wiley, 1938, Fig. 43.)

when the stimulus has a low energy content, loudness varies most with energy. In the region of 100 decibels, a great shift in decibels varies loudness but little. The curves for many of the various frequencies tend to converge as loudness increases. It turns out that a loudness of 100 sones is produced by an energy of little more than 100 decibels for most of the frequencies shown.

A scale for pitch in mels

In essence the same procedure was used by Stevens, Volkmann, and Newman (1937) to construct a scale for pitch. Figure 10.5 shows a curve

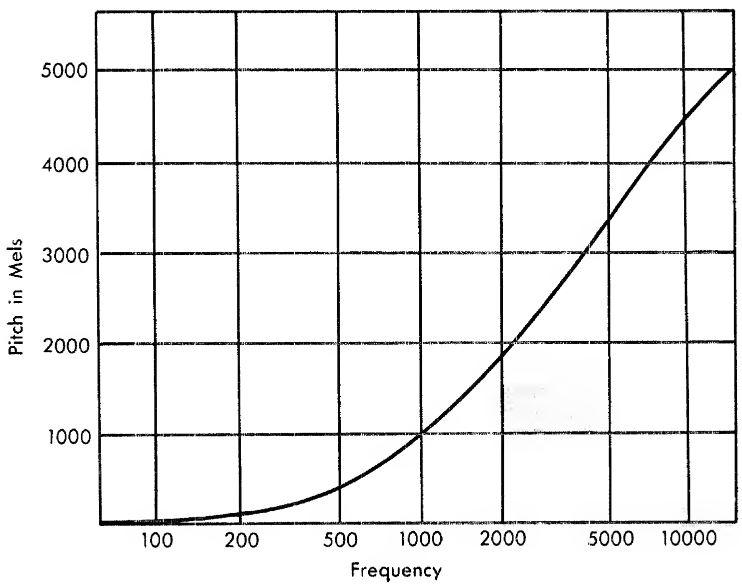


Fig. 10.5. The relation between frequency and pitch in mels. (S. S. Stevens, J. Volkmann, & E. B. Newman. A scale for the measurement of the psychological magnitude: Pitch, *J. acoust. Soc. Amer.*, 1937, 8, 185–190.)

relating pitch and frequency. It will be noted that except for tones produced by sources having frequencies of less than 1000 cycles per second, the relation of pitch to frequency is almost linear. The unit of pitch used by the investigators just mentioned was the *mel*. It is so defined that the pitch heard is 1000 mels when the energy level is 60 decibels and the frequency is 1000 cycles per second. In other words, a source had to be chosen that was considerably above the one that would produce the pitch unit of the convenient size. A 1000-cycle source was chosen. The pitch heard could not be called one mel, for that would reduce the whole frequency scale to

production of a range of only 5 mels. So the 1000-cycle tone was called 1000 mels, and the scale was worked out for sources both lower and higher in frequency, using 1000 cycles as a standard.

AUDITORY THRESHOLDS

The measurement of the thresholds for hearing at a series of representative frequencies is called *audiometry* and is generally done by use of an instrument designed especially for the purpose. Such instruments are electronic devices consisting in audio-frequency oscillators constructed to generate eight or more fixed frequencies. These relate to each other as octaves from, let us say, 64 cycles to 8192 cycles. This instrument is calibrated in "sensation units," for which the decibel scale is used, its zero point being the average threshold for the normal ear. The intensity in decibels that the energy at the given frequency must be stepped up above zero is stated as the hearing loss for that frequency. When all the frequencies have been tested, a profile or audiogram is constructed (Fig. 10.6). The dotted line in Fig. 10.6 is a curve showing the losses defining the "total loss of serviceable hearing." Some large-scale studies have shown that in males age has no

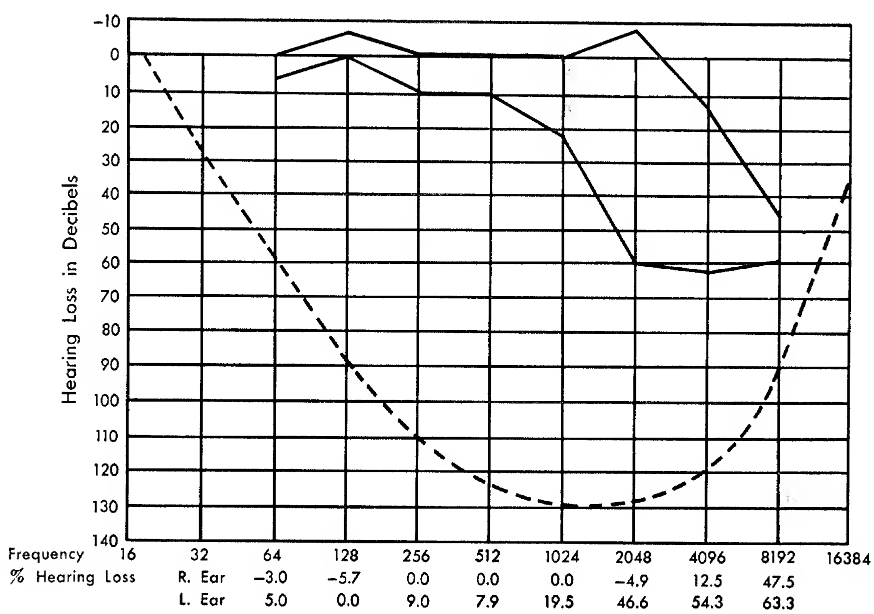


Fig. 10.6. Audiogram of a case of high-tone deafness. The solid line on top is for the right ear, and the solid line below it is for the left ear. (S. S. Stevens & H. Davis. *Hearing: Its psychology and physiology*. New York: Wiley, 1938, Fig. 20.)

impairing effects for frequencies below 1000 cycles but that considerable losses do occur at high frequencies, that is, at 4096 and 8192 cycles. The average loss there was about 31 decibels. Females manifest material loss for low frequencies but less for higher frequencies. Curious as it may seem, the sex differences are marked. One feature of this is that men show more frequent partial loss for high frequencies than do women.

Hearing loss

Some hearing loss is such that the impaired ear provides for hearing less well at all acoustic-energy levels. In another form of hearing loss, hearing is as good as normal for acoustic energies well above threshold. In the third type of hearing loss, hearing improves relatively as intensities are increased but never reaches normal. This is of course a case intermediate between the other two. In the first type of hearing loss, it may be assumed that the effects are reduced somewhere in the auditory pathway before reaching the cerebral cortex; this type of hearing loss is the common result with defects in the middle ear.

The second type of hearing defect is as if there was the same absolute loss in terms of sones for all intensities. This would be expected if there was a deficiency in the total number of neural elements involved; we might call it a case of "nerve deafness." In dealing with this sort of deficiency we could subtract a given constant amount of "loudness." Thus, as intensity is increased and the relation between loudness in sones and the decibels of energy in the stimulus shifts, such deaf persons could "catch up" with the normal individual. (Refer to Fig. 10.4, which gives the relation of sones to decibels.)

Threshold differences in onset

One problem that has both theoretical and practical significance is the question of how different two sources may be in time of onset and still be perceived as beginning simultaneously. Bürck, Kotowski, and Lichte (1935) determined this. It seems that the time intervals involved are fairly similar to the time needed to recognize the tonal quality of sound. If the first source begins long enough before the second source begins, so that the first produces a sound whose tone is recognized, then the second source will produce a second tone. That is, two successive tones will be heard.

PITCH

Pitch and loudness

In our definition of a sone, we recognized that loudness depends not only on energy input but also upon the vibration frequency; a frequency of

1000 cycles per second was chosen as a standard. We can now ask what the relation is between loudness and frequency. We are in effect asking for the relation between units pertaining to response and a characteristic of the input. The direct way of answering this experimentally would be to vary the frequency and determine the change in pitch. Since pitch is expressed quantitatively in mels, we would be plotting mels against frequency. But because the human observer cannot respond by reporting directly in terms of mels, experimentation has to proceed in some other way.

One method is to vary the frequency of the stimulus and determine whether or not pitch changes; least change in frequency that will produce a change in pitch can be determined. The result is JNDs, or just-noticeable differences. If we choose a series of standards throughout the entire frequency range, we can determine the JND at each point, which would provide data for a plot of JNDs against frequency.

Another way to proceed is to vary intensity (not loudness) and find the change in frequency required to maintain a constant pitch. In Fig. 10.7 the change in frequency is expressed in percent. The intensity level ranges up and down from a midvalue. From the figure it will be noted that for frequencies ranging between 1000 and 3000 cycles per second little change in frequency is required to maintain constant pitch as intensity is varied up or down. For higher frequencies, greater percentage shifts in frequency are required with concomitant intensity changes. Or, to put it another way, as intensity is varied greater shifts in frequency are produced. For frequencies lower than 1000 the same thing happens, but whereas increase in intensity raises pitch for the high frequencies when frequency is held constant, the opposite happens for low frequency standards. Thus pitch is lowered as intensity is raised.

Pitch and duration

When an acoustic source lasts for less than one second, the phenomenal (or perceptual) effect is a click rather than a tone. One might suspect that a click would have no pitch, but this is not strictly the case. Some clicks sound higher than others. The ear acts as an analyzer, even for short acoustic stimuli; thus, some clicks sound sharp and others sound dull and lower in pitch. Stevens and Davis (1938) discussed how this analysis takes place. Figure 10.8 indicates the relations Stevens and Ekdahl (1939) found between duration of a tonal source and pitch.

Bürck, Kotowski, and Lichte (1935) studied the relation between the minimum duration of a sound stimulus and its frequency in order for the listener to experience a definite pitch. A source with a frequency of 50 cycles per second must last for 60 milliseconds, whereas a source with a frequency of 1000 cycles need last only a little longer than 10 milliseconds.

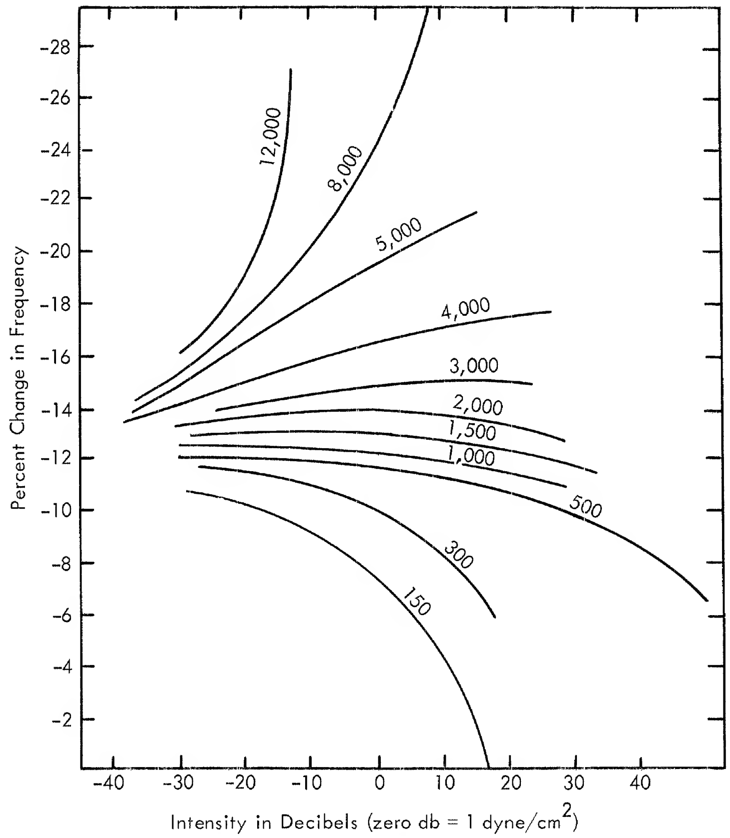


Fig. 10.7. The relation between frequency and intensity to maintain a constant pitch. The curves show percent changes in frequency needed for acoustic sources of various frequency as intensity is varied. (S. S. Stevens & H. Davis. *Hearing: Its psychology and physiology.* New York: Wiley, 1938, Fig. 23.)

Obviously, the latter source will involve twelve pressure waves in that time, whereas the first source would produce about three waves in 60 milliseconds.

Pitch from complex wave forms

When a complex tone is produced by frequencies differing by a constant value, let us say of 100 cycles or more, the pitch is not the pitch expected from a frequency represented by the mean of the frequencies acting but rather the pitch produced by a source whose frequency is equal to the constant difference between the frequencies. Let us say that the component frequencies of the complex acoustic source are 800, 900, 1000, and 1100 cycles. Such a source produces a perceived tone expected from a stimulus of

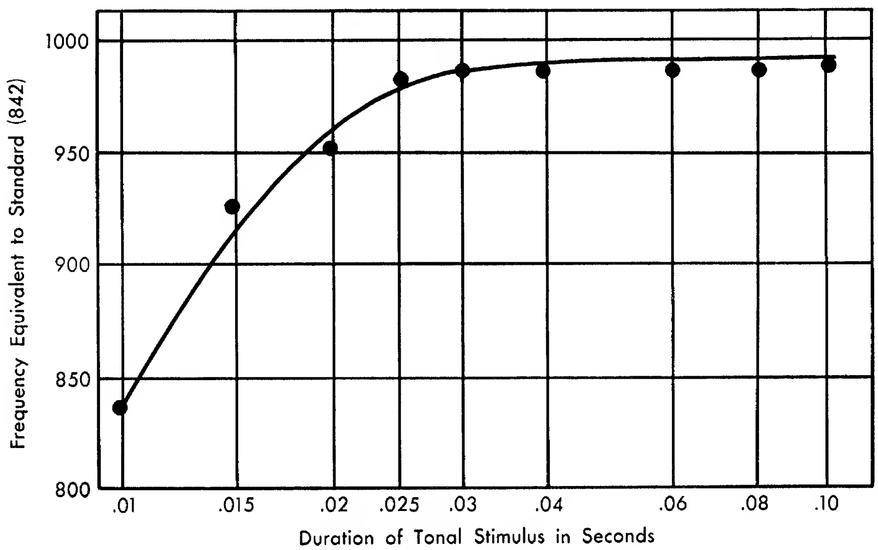


Fig. 10.8. Relation of pitch to duration. (Ekdahl and Stevens. Cited in S. S. Stevens & H. Davis. *Hearing: Its psychology and physiology*. New York: Wiley, 1938, Fig. 36.)

100 cycles. By the same principle, a complex source composed of frequencies of 500, 700, and 900 cycles produces a pitch expected from a source with a frequency of 200 cycles. Furthermore, if to a complex acoustic source composed of frequencies of 400, 600, 800, and 1000 cycles the additional frequencies 500, 700, and 900 are added, the pitch seems to drop a whole octave, namely, from a pitch produced by 200 cycles to one produced by 100 cycles.

This principle was reported many years ago by Fletcher (1934) at the Bell Telephone Laboratories. In addition to these findings, certain very unexpected results in connection with filtering out certain frequencies of a complex sound source were obtained. The common understanding with regard to the pitch produced by a complex source is that the pitch depends upon the frequency of the *fundamental* component, the component with the lowest frequency. The other frequencies, being all higher, are called the *overtones* and are expected to affect timbre but not pitch.

Let us say that the complex source with which we are dealing contains a fundamental of 300. The first overtone will be a frequency of 600; the second overtone will be a frequency of 900. Thus there is a common frequency *difference* between the component tones, and the sound produced will be a tone that is expected from a frequency of 300 cycles. This allows us to eliminate the fundamental, just so long as the remaining components still possess the constant frequency difference. All that this means is that, usually, in order to get a set of frequencies differing by a constant fre-

quency value, a wave of this very frequency is one of the components produced by the source. The physical characteristics of the acoustic source are such as to vibrate at a given rate and at any one of several higher rates that are multiples of the lowest rate, the fundamental. If certain overtones are somehow left out or greatly reduced, we may expect a rather indefinite tonal effect.

LOUDNESS

Loudness and duration

Just as in the experience of pitch, the experience of loudness depends upon the duration of the acoustic stimulus. When it is very short, the loudness is at its minimum. As duration increases, the loudness grows, finally reaching a maximum. With further increase of duration, the loudness diminishes to a stable value. This is reminiscent of the brightness produced by a photic stimulus, and therefore helps to unify our understanding of the way the organism operates. According to Békésy (1933), acoustic stimuli lasting less than one-half second are heard as less loud than those that are longer.

One hypothesis covering the relation between loudness and duration, stated by Licklider (1951), is the *diverted input hypothesis,* according to which a constant portion of the acoustic input (power) is diverted from the excitation process and therefore is not integrated in producing the sensory end result. The threshold function can be stated by

$$(I - I_0)t = \text{constant}$$

This means that the impingement minus a certain fixed fraction multiplied by the duration of application is a constant. The relationships just mentioned apply not only to the absolute threshold but also to differential thresholds.

Masking

If two acoustic energies of different frequency and different intensity impinge on one ear, the weaker energy may not be effective at all. This is called *masking.* The weaker source may of course be made to be heard by intensifying it. Masking is measured by determining the amount by which the threshold of one acoustic source is raised by the presence of another. The masking effect extends over considerable ranges of difference in frequency but is greatest for tones of nearly similar frequencies. One frequency will mask a higher frequency more easily than one of a lower frequency.

The language used in the literature has varied and it has not always been clear as to what the term masking refers to. It may refer to input

(the impingement or stimulus), in which case it would be said that one acoustic source may mask another. That is, the listener would hear only one of the two acoustic sources, although it is known that the vibrations from both reach the ear.

Masking may refer to some operation (or activity) in the mechanical or neural mechanism of the ear, in which case it would be implied that one activity masked (covered up) the activity of the other, although both activities would actually be there.

Masking may refer to the sensory experience (the sensation) itself, in which case it would be implied that there are actually two experiences but one covers the other up. It should be obvious that no such result is possible, for by definition a sensation is something *experienced*. There could be no such thing as an unexperienced or nonexperienced experience. The concept of masking is thus a subtle one that does not have the virtue that its growing use seems superficially to imply. It does not apply in some of the ways it has been used. Sophistication in psychology and related disciplines demands that this be recognized.

Wegel and Lane (1924) depicted the various auditory effects of using two acoustic sources, one of which is called the primary source, the other the secondary source. The primary source was at 1200 cycles and 80 decibels in intensity. The secondary source varied both in frequency and in intensity. Figure 10.9 shows the effects produced. At first glance the figure looks forbiddingly complex, but we can make it intelligible and significant by describing examples of various source combinations and indicating the auditory results produced.

Let us begin by noting the solid curve at the bottom left of the figure, keeping in mind that the primary source is at a fixed frequency of 1200 cycles, as indicated on the horizontal axis, and at 80 decibels, as indicated on the vertical axis of the diagram.

If the secondary source is below 1200 cycles and is increased from a subaudible level to a value that is just audible, it is first heard as a separate tone in addition to the primary tone. The area of the diagram below the dotted line indicates the level at which the tone can be raised and still be heard as a separate tone. When the intensity of the source is raised further, a difference tone emerges, and with still higher intensities the overall effect is spoken of as a mixture of tones. However, if the frequency of the secondary source is close to 1200 cycles, either slightly below or slightly above, *beats* are heard (see page 282).

A very different effect is produced as the frequency of the secondary tone is raised somewhat above 1200 cycles. Unless the secondary source is quite intense, only the primary source is heard ("masking"). In the range of from 1200 to 2400 cycles, an octave, if the secondary source is raised enough, both sources will be effective. The secondary source will be effective to the extent that it will participate in producing a difference tone. Thus, the primary tone and a difference tone will be heard.

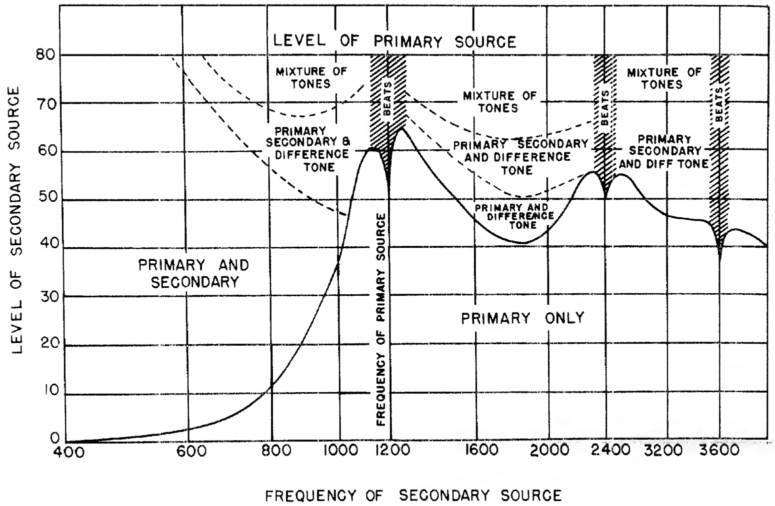


Fig. 10.9. Auditory effects from using primary and secondary acoustic sources. The primary source is held at 1200 cycles per second and at 80 decibels. The secondary source is varied both in frequency and intensity. (R. L. Wegel & C. E. Lane. The auditory masking of one pure tone by another and its probable relation to the dynamics of the inner ear. *Phys. Rev.*, 1924, **23**, 266–285, Fig. 5.)

If the intensity of the secondary source is raised still further, a primary, a secondary, and a difference tone will be heard. With still more energy put into the secondary source, a "mixture of tones" will be heard. When the secondary source approaches 2400 cycles, beats will be set up as in the octave below.

When the secondary source ranges from a little above 2400 to close to 3600, the effects are as labeled in the diagram.

TONAL QUALITY

Tones, overtones, and timbre

The acoustic sources producing single frequencies are called *tonal.* The sources that produce groups of waves that relate to each other according to simple whole numbers are also called tonal. Other acoustic sources are *atonal,* or noise-producing sources. The waves of the tonal sources are of two classes: the lowest frequency is the *fundamental,* and the others are *overtones.*

It will be fairly obvious that there are several primary variables involved—wave frequency, wave amplitude, and degree of simplicity or complexity of the wave pattern. Insofar as a single frequency dominates, the

result is a perceptual quality called pitch. The amplitude of the waves, insofar as the waves do not cancel, provides loudness. The complexity of the wave pattern provides for distinctions between tones, noises, and numbers of separate tones heard at once. Tonal sources can be distinguished from each other in terms of the number and relative strengths of the overtones. That is, a violin can of course be distinguished from a French horn or an oboe or a piano. This is on the basis of *timbre*. This assertion has been checked on many times by way of demonstrating that the sounds of various musical instruments can be synthetically produced by combining various wave frequencies of various amplitudes. This was first done in the nineteenth century when experimentalists as their first step analyzed the sound sources by means of resonators. Nowadays we have electronic organs, the tones of which are all produced by electric oscillations that activate speakers (that is, diaphragms) electromagnetically. Various frequencies can be blended to similate well-known musical instruments in addition to the organ tones themselves.

Combination tones and beats

Combination tones are formed by two frequencies being presented simultaneously. Not only are the tones arising from each of the single sources heard but also the tone that would be produced by a frequency that is the sum of the two frequencies actually generated as stimuli and the tone expected from a frequency that is the difference between the two frequencies of the stimuli. These two extra tones are called *summation tones* and *difference tones*, respectively. Not only may there be a first-order difference tone and summation tone but there may also be second-, third-, and possibly fourth-order tones. It is doubtful, however, whether most persons could hear the second- and higher-order tones.

When two frequencies do not differ greatly enough to generate difference tones, a third phenomenon may occur. The difference in frequency may generate a low frequency variation called a *beat*, or low-frequency waxing and waning of the loudness of the tones. One knows by the number of these waxings and wanings what the frequency difference is between two stimuli producing closely similar tones.

Consonance and dissonance

One major factor in hearing is not generally treated as a quantitative matter but is nevertheless an indubitable aspect of tones: consonance and its opposite, dissonance. When two frequencies are generated at the same time, the listener will hear either a pleasing or a displeasing sound. Some tones are heard as fusing and blending well. Others are described as jarring, rasping, or clashing. Perhaps this qualitative effect is nothing that can be

considered stable and similar among all people. Sounds have meaning and can take on new meanings, and it is possible that what is called consonance and dissonance may have some basis in the listener's system of meanings and habits. In our society, the frequencies that have long been considered consonant are those having a ratio of 2:1 (the octave), 3:2 (the major fifth), 4:3 (the fourth), 5:3 (the major sixth), 5:4 (the major third), 6:5 (the minor third), and 8:5 (the minor sixth). The first three are better than the last four; it is with reference to goodness among these ratios that listeners differ even while calling them all consonant.

Frequency ratios that are called dissonant are 9:8 (the major second), 15:8 (the major seventh), and so on. Among the theories accounting for consonance and dissonance is Helmholtz's (1930), which has to do with overtones causing beats. It has been found that dissonance does not disappear when pure tones occur, and this has been used as an argument against Helmholtz's theory. It has been pointed out, however, that the tissues of the ear may be made to vibrate with harmonics even when the acoustic source lacks them. Hence, harmonics in the ear itself may be produced and may support Helmholtz's idea.

Volume

Certain writers have referred to a characteristic of tones called volume. Low tones of an organ, for example, sound bigger and more space-occupying than the squeak of a mouse. Even when two sounds are equated for loudness, the difference called volume persists. Volume is used in another way, too. We should not confuse the two meanings. Radio sets have volume controls, and when volume is dealt with in this way, it is intensity that is being manipulated. As far as the listener is concerned, of course, it is loudness that is consequently varied.

The property of volume as bigness has been studied by several workers. Volume was first studied as a function of stimulus frequency. Later it was studied as a function of stimulus intensity. The thinking behind these attempts was that, if the difference limens for volume are different from those for pitch and loudness, then volume as an attribute of tones is different from either of the other two. In other words, if its threshold is different, it follows different laws and so is a unique attribute. The results of various workers in testing the threshold have not agreed. Despite this, there seems to be evidence from listeners that there is such an attribute as volume and that it is distinct from the other two attributes.

Stevens (1934b) finally established that volume is a tonal attribute. In his investigation, the observer was given stimuli of unlike frequency producing alternately different tones of different pitch. He varied the intensity of one stimulus until it matched the other in volume. This procedure established the fact that the two tones could be made equal in volume

while being experientially different in pitch and loudness. To maintain equality in volume, all sources had to be increased in intensity as they were increased in frequency. That is, as pitch was raised, the experience had to be increased in loudness to maintain a fixed volume. The shift had to be greater for a low intensity input than for a higher one.

The slopes of the curves in Fig. 10.10 indicate that at low intensities the relative effectiveness of intensity is less than that of frequency in determining volume. At high intensities, the opposite is true. The graph is so constructed that as the intensity and the frequency of certain sources are varied above and below a given common reference point, shown at the center of the diagram, the equal-volume conditions vary as represented by the curves. Stepping up frequency of a source requires that its intensity be

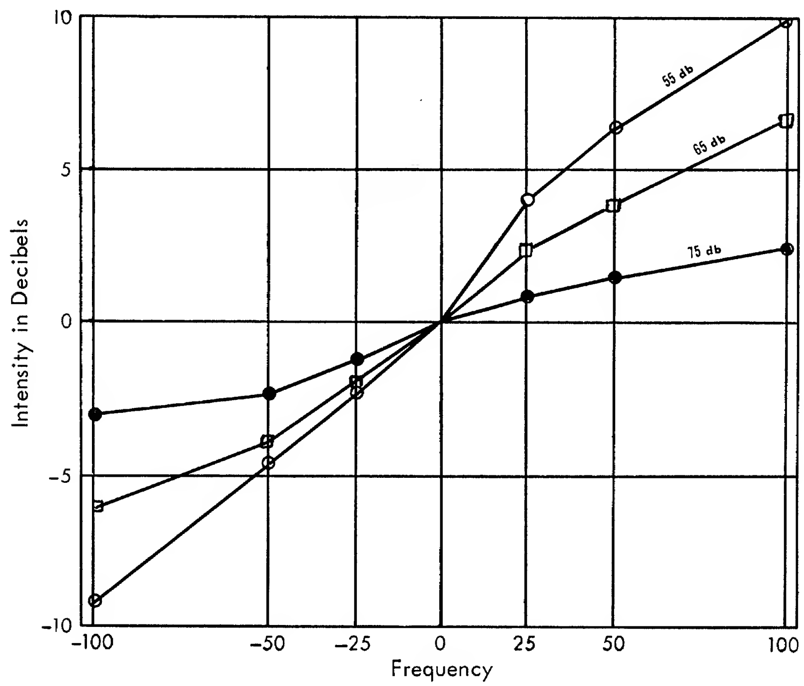


Fig. 10.10. Equal volume curves showing how volume is kept constant by manipulation of intensity and frequency. Each curve is for a constant volume but a different intensity. Open circles are 55 decibels; open squares are 65 decibels; solid circles are 75 decibels. (S. S. Stevens. The volume and intensity of tones. *Amer. J. Psychol.*, 1934, **46**, 397–408, Fig. 1.)

stepped up also if equality of volume is to be maintained between the two resulting tones. The slopes of the three curves, each curve representing a fixed intensity, show that this relation is more marked for lower intensities than for higher ones.

Tonal density

Observers have declared that some tones have a fourth possible attribute, sounding denser, tighter, or harder than others. Stevens (1934a) obtained the differences of two stimulus values that would result in tones that were equal in density but not in loudness. In this way he showed that there was no confusion between density and loudness in the behavior of the observers. Figure 10.11 indicates the relation between density and fre-

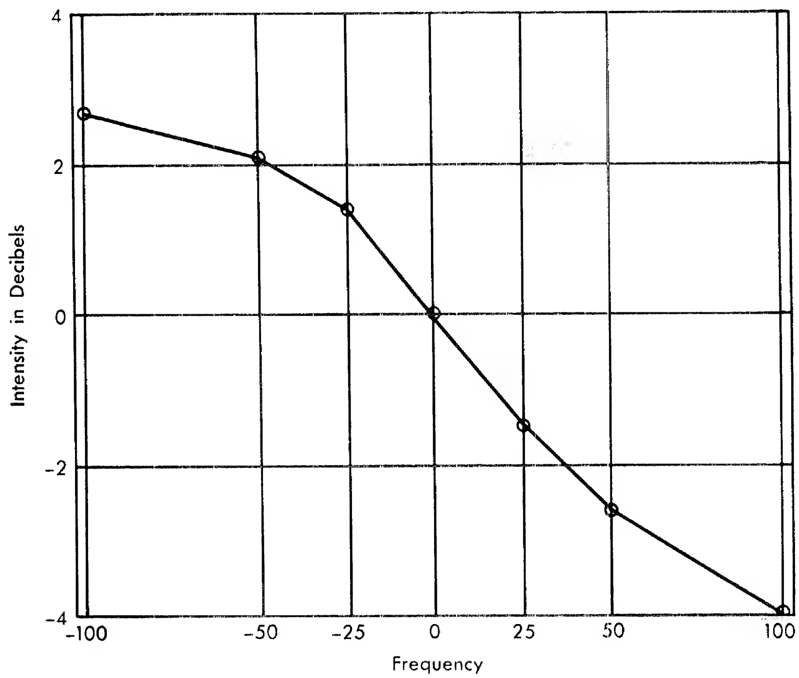


Fig. 10.11. Equal density curve showing how a difference in frequency can be offset by a difference in intensity to keep density constant. (S. S. Stevens. Tonal density. *J. exp. Psychol.*, 1934, 17, 585–592, Fig. 1.)

quency and loudness. Comparison between this set of relations and the behavior of volume can be made by turning back to Fig. 10.10; the two functions run in opposite directions.

Brightness of tone

A fifth term, *brightness*, has often been used by observers to describe the quality of the tones they hear. Again, several investigators addressed themselves to the task of finding the operations that had to be performed

to manipulate the quality that the observers alleged. There is no doubt that many observers find the terms bright and dull to be quite aptly descriptive of the tones they hear. Some investigators identified, or at least closely associated, brightness with pitch. This led, of course, to the assumption that the two characteristics for a single operational dimension.

Abraham (1920) thought he had demonstrated that pitch and brightness are actually independent by showing that, with a Seebeck siren, tones differing in brightness could be produced by the same frequency. Boring and Stevens (1936) examined the claim and found that the difference between Abraham's tones was produced by a difference in the proportion of some of the higher overtones present. The observers also called the louder of the tones the brighter. Brightness was thus found to be a function of the combined operation of the dominant wave components of a sound source and its intensity. This does not make brightness a myth but, since density seems to be a similar function of frequency and intensity, brightness and density may be two words for the same experience.

Observers can equate two pure tones (produced by a single frequency) in brightness, but they are unable to do so once brightness is declared to be something other than what they were calling density. There just do not seem to be two distinguishable characteristics amenable to this treatment. It will be remembered that brightness is mostly used in vision rather than in hearing. Since the term is used in two modalities, one might construct an experiment to equate brightness of tones and brightness in visual targets, which would be to ask whether a given tone is as bright as a given surface and to deal with brightness by fractionation. If a tone is capable of being judged as bright as a given visual presentation, can it be judged half as bright or twice as bright? The attempt to make such judgment might add to our understanding of tonal experience. (This procedure was utilized in making comparisons between very unlike qualities such as saltiness, sourness, bitterness, and sweetness, and it will be discussed in Chapter Fourteen.)

INTERMITTENT ACOUSTIC STIMULATION

The use of intermittent photic stimulation was described in Chapter Four. It has been shown that intermittent acoustic stimulation can be used in a somewhat similar manner.

Miller and Taylor (1948) demonstrated this for two subjects. One measure used in photic stimulation was critical flicker frequency, the rate at which a repetitive brief photic pulse just produces the experience of continuous uniform light. Sometimes restricted portions of the spectrum were used in this manner, but more often a stimulus producing the experience of whiteness or its approximation was used. The stimulus used in the intermittent acoustic presentation was a source involving a heterogeneous com-

plex of frequencies. In the conventional vernacular, this stimulus is known as *white noise*.

Although both photic and acoustic energies can be presented intermittently in systematic fashion and produce stable, repeatable results in perception, some differences in the conditions should be pointed out. The auditory mechanism is sensitive differentially in higher frequency ranges of intermittence to the visual mechanism. Critical flicker frqequency (CFF) probably never exceeds 60 cycles per second. In contrast to this, auditory flutter may still exist at up to 1000 cycles per second. Another difference lies in the fact that the threshold for the disappearance of auditory flutter is not so stable as for the disappearance of visual flicker. It is said that some intermittent acoustic stimuli may be productive of fused or unfused sound almost at the will of the observer. This makes it a serious problem to establish suitable criteria for the study of the flutter disappearance threshold (or AFF, auditory flutter fusion).

The crucial shift in the perception produced by intermittent stimulation takes place between what Miller and Taylor call Stages 3 and 4. It is a shift from a perceived quality different from continuous noise to a quality not different from continuous noise. This seems to call for an experimental procedure in which pairs of stimuli are presented, one intermittent and the other continuous. The subject is instructed to indicate by calling out "different" for any pair in which the sounds are not perceived as identical.

In addition to intermittence rate, there are other important variables for producing AFF. One is the fraction of the cycle occupied by the stimulus. In photic stimulation this is called PCF (pulse-to-cycle fraction). Another factor is the energy in the stimulus. Still additional factors are the distribution of the energy within the group of frequencies used and the rise-and-fall times of the stimulus envelope.

Symmes, Chapman, and Halstead (1955) studied AFF for three stimulus intensities as the fraction of the cycle occupied by the stimulus was varied against frequency. The bursts used were 1.5 seconds long, the intrapair interval was 1 second, and the interpair interval was 2 seconds. The descending method of limits was used. Figure 10.12 shows the results for a single observer. It will be noted that the lower portions of the three curves manifest a slope of about 45°, which is to be expected if the duration of the off interval in the cycle is the determining factor in the fusion function. The upper portions of the curves manifest slopes of steepness less than 45°. This was believed to represent a change in the listener's acuity. From the information they had, the workers were able to formulate an equation for the flutter-fusion function:

$$f = 1000\left(\frac{I\,c}{\Delta I\,T}\right)$$

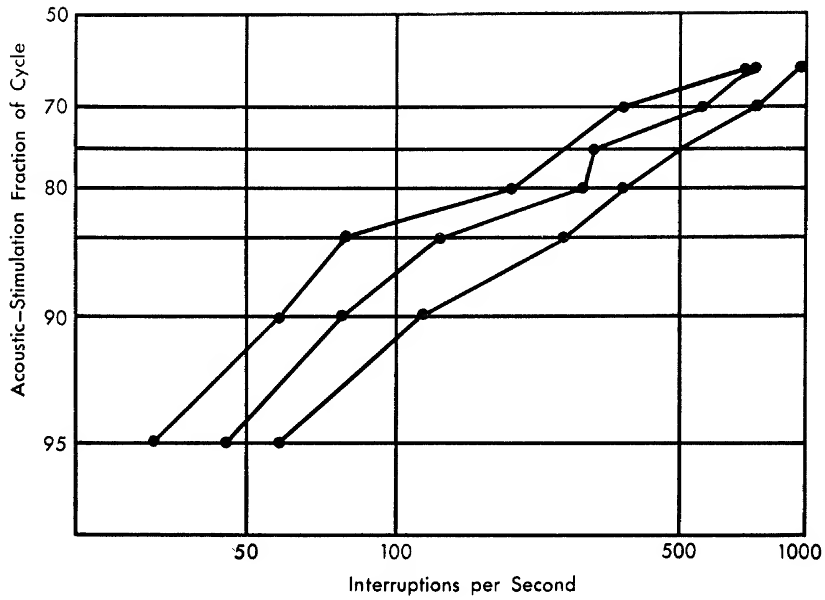


Fig. 10.12. Auditory-flutter-fusion thresholds of one observer. The top curve is for 45 decibels, the middle curve 60 decibels, and the bottom 80 decibels. (D. Symmes, L. F. Chapman, & W. C. Halstead. Fusion of intermittent white noise. *J. acoust. Soc. Amer.*, 1955, 27, 470–473, Fig. 1.)

where f is the repetition rate at fusion threshold, I is the intensity of the stimulus in decibels above threshold, ΔI is the intensity JND (just-noticeable difference) for noise in decibels, t is the duration of the experienced decay to threshold in milliseconds, and c is 1 minus the fraction of the cycle occupied by the stimulus. Using the equation provided adequate predictions for values for the lower parts of the curves in Fig. 10.12 but not for the upper portions. The authors suggested four propositions with regard to the mechanisms at work to account for the discrepancies, but they are too involved for presentation here.

THEORIES OF HEARING

The theories of hearing possess two main components. The first has to do with the effects of the vibratory impingement upon the ear in a mechanical way. The second has to do with the relation of vibration frequency and the activities set up in the neural part of the ear. Békésy has had more to do with the clarification of the first component, and a series of other workers led by Wever and Bray have contributed to understanding and describing the second component. During the several decades before the advent of the more recent experimental penetration into the mechan-

isms of the ear, Max F. Meyer (1873–1967), a psychologist, played the most persistent role in describing how impingement operates on the ears.

Theories of hearing have primarily to do with pitch and its relation to the vibration frequency of the stimulus. It is generally agreed that the two factors mentioned above are involved. More precisely, they are (1) a kind of differential response from portions of the cochlea along its longitudinal axis, thus making the *place* of maximum mechanical response in relation to the neural elements there discriminate frequency, and (2) certain restrictive relations regarding input frequency and the ability of neural elements to respond. Classically, there have thus been two forms of theory: one a *place* theory of hearing and a *frequency* or *periodicity* theory.

Helmholtz in his day was the proponent of a *resonance* theory, a form of place theory. He supposed that the structure of the inner ear was such that the various portions of the cochlea along its longitudinal axis were resonators for specific frequencies. Thus his theory implied the sharpest and the "finest grained" relation between the ear's mechanics and the setting up of impulses in the auditory nerve and the production of different pitches.

The fact that the organism can detect the presence of various frequencies in an acoustical wave and identify them by hearing pitch, if they are not too numerous or too trivial, is called *Ohm's acoustical law*. The auditory mechanism (presumably the ear) acts as though it possesses a set of resonators. Helmholtz showed by an actual series of resonators what the components of a complex acoustic source are. He noted which resonators respond (and how much) and which do not. To do a satisfactory job of acoustic analysis by this method, a huge number of resonators would be needed, and hence the method is little used.

The work of Békésy (1947) provides a description of the mechanics of what happens in the ear and demonstrates the fallacy of supposing the actual existence of a set of resonators. The ear accomplishes its analysis by a different method. The cochlear bulge produced at each compression phase of the impact on the oval window is a traveling wave in the cochlea. The bulge for high frequency inputs travels a short distance, producing a peak, and dies out. Vibration inputs of low frequency travel farther (depending upon how low the frequency is) before peaking and damping out. Thus, peaks can be mapped for different frequencies. This is a *place* factor. But, for low frequency inputs, the bulge is not as restricted as for those of high frequency. More and more of the cochlea is involved in the bulge and so the principle of selective effect according to place fades as a simple factor. By depending upon this selectivity, one does not explain how the ear provides for the individual's hearing low frequencies. Since we know that the listener can distinguish well between two frequencies in the low range, some other mechanism in the ear must be sought either to supplant or to supplement a place theory. This necessity has led to reliance upon

periodicity as a factor. It is generally assumed nowadays that both the place factor and the periodicity factor operate.

The periodicity factor is expressed by the fact that the neural elements, by reason of their own periodicities, can follow cycles of the input by being able to discharge and recover once per cycle. This can be expected to apply to any element just so long as input frequency does not become too high. While the input frequencies are low enough, individual neural elements can respond at the input rate and thus the central nervous system is provided a differential neural input directly in terms of the neural discharge frequency itself.

With the realization that the maximal discharge rates of neural elements cannot keep pace with the higher ranges of input frequencies, the problem of explaining pitch is not fully solved by the description thus far. Wever and Bray (1930) formulated as a solution what is known as the *volley theory* to account for how the activity in the auditory nerve could be discriminatory although the single neural elements are unable to follow the highest stimulus input frequencies. This theory supposed that although none of the elements could repeatedly fire at rates required to follow, one to one, the input frequency, they could fire to alternate or at every third, fourth, or *n*th cycle of the input. Thus, if some fired to one cycle and others to others, a fraction of the total neural element population would be firing at every cycle regardless of how high the input frequency would become.

This theory and the alternation-of-response theory describing the visual system's reaction to photic input are in many respects the same. While it can be said that the auditory theory preceded the visual theory, the visual theory was not formulated with the auditory theory in mind.

The response in the auditory nerve has been analyzed by employing acoustic stimuli varying in frequency from low to high. With a stimulus of 1000 cycles or less, a fairly regular burst of impulses is produced for every cycle. In a range of from 2000 to 4000 cycles, the overall action potential of the nerve still follows the stimulus frequency pretty well. A difference has crept in, however; the amplitude of the burst of impulses for each cycle has become considerably smaller. This was interpreted as indicating that not all individual neural elements were firing (responding) to each cycle of the stimulus. Some were responding to every second cycle or relatively less often than that. This evidence for the failure of neural elements to respond to all cycles becomes more convincing as input frequency rises. As has already been implied, there is random staggering so that all cycles come to be responded to by equal numbers of elements. At above 4000 cycles per second, the overall record fails to show the following-characteristic at lower frequencies, and synchrony can no longer be detected in the overall response. The elements beginning to be activated and those going in to the recovery phase at all instants balance out to a uniform, continuous, overall amount of activity.

The theory involves another one of the same assumptions that is involved in the alternation-of-response theory in vision, namely, that the latencies and recovery rates of single neural elements are not totally identical. This variance is a factor contributing to the temporal staggering (or desynchronization) of elements in the overall response, just described (It may be well to point out that the same principle will be encountered in the depiction of the tactual and the kinesthetic modalities in Chapter Twelve.)

SUMMARY

Following some introductory remarks the chapter was divided into about nine major topics: the acoustic stimulus, the ear, auditory scaling, auditory thresholds, pitch, loudness, tonal quality, intermittent stimuli, and theories of hearing.

The chapter described how Békésy pointed out that there are at least six ways that hearing can be produced. The principal anatomical features of the ear were described. In the section on auditory scaling, the unit called the decibel was described, as well as the procedures for establishing the two major sensory scales (the sone scale and the mel scale). Various other investigations on pitch and loudness were discussed. The section on pitch included the topics of the relation of pitch and duration and pitch from complex wave forms. The section on auditory thresholds dealt with audiometry and hearing loss.

In the section on loudness, the concept of masking was discussed and criticized. Tones, overtones, and timbre were dealt with in the next section, followed by sections on consonance and dissonance, tonal volume, tonal density, and brightness of tone.

The effects of using intermittent acoustic stimuli were included in the next section. The chapter concluded with a brief discussion of theories regarding hearing—the Wever-Bray theory, for example.

ELEVEN

Auditory Perception

This chapter considers first the topics of externalization of sound, auditory localization, the relation of reverberation to perceived distance, the matching of auditory and visual perspective, and sounds as abstract symbols. Then it takes up the perception of speech, which, though not too familiar a topic, is quite in line with the general theme of the book, namely, to describe the relation of the organism to its physical surrounds.

AUDITORY SPACE PERCEPTION

Externalization of sound

In Chapter Seven the way that the auditory mechanism might function to provide the apprehension and appreciation of external space was discussed. It was emphasized there that the auditory mechanism does not include the facilities that would enable it to take a role in initiating the perception of space as a domain.

One investigation that bears on this point and is appropriate here is the study of the localization of tones produced by earphones. It was found that the resulting tones were localized within or near to the head, which is different from the localization that results when the same tones are produced in the more usual way, that is, by sources at some distance from the ears. In the one case the subject cannot manipulate his geometrical relationships to the source, whereas in the other he can. This difference may be one factor in producing the perceptual difference in the two cases.

Our chief interest in the fact that sounds produced by external sources

may seem to originate *within* the body rather than outside it lies in its demonstration that all sounds do not have to pertain to *externality* even in the sighted. Those who know most about blindness assert that acoustic stimuli are not intrinsically interpreted as being localized *externally* by the congenitally blind. The example of the headphones helps to make this assertion seem more plausible.

In vision, movement of the perceiver and change of optical information from space as a domain go hand in hand in a very direct manner. Persons with hearing but no vision have much less opportunity to relate their sensory experiences to externality. The main thing that the person without vision can do is move his head or whole body so as to manipulate intensity and phase relations of acoustic waves, a gross affair compared to the achievements possible with vision. When motor manipulations are to be made by the blind in relation to hearing, they are related to the body as a domain rather than to externality. We would assume that the congenitally blind are not able to get away from the body as a reference. In fact, it would seem that the burden of proof would rest on those who assume that the congenitally blind do experience externality (see Chapter Seven).

Localization

Newman (1948) summarized well the nature of sound localization as far as its accuracy is concerned. He pointed out the characteristics as follows: (1) The subject almost never confuses an acoustic source on the right with one on the left. (2) He may occasionally report hearing a sound behind him when its source is in front or overhead. He may hear a sound as located to the right and in front of him when its source is to the right and behind him. (3) In general, the sort of confusion that may take place when the source is off to one side of the median plane is describable by means of a cone whose apex lies at the center of the head (Fig. 11.1). Any position on the cone may be confused with any other position on it. Points on the cone's surface represent both a set of directions and a set of distances (although we are mainly dealing with a set of directions). Hence, the opposite sides of the cone represent the extreme amounts of discrepancy in direction between acoustic source and the sound heard. Lesser discrepancies are represented by various points within the cone at constant distances from the ear. The cone is the best descriptive device to picture range and combination of positions of two acoustic sources that would tend to be confused with each other, that is, those that would seem to be identical.

VERTICAL LOCALIZATION. The localization of sounds in the vertical dimension is very poor in the sighted person when the head and the sound source do not move. The listener must move his head in order to do much at all

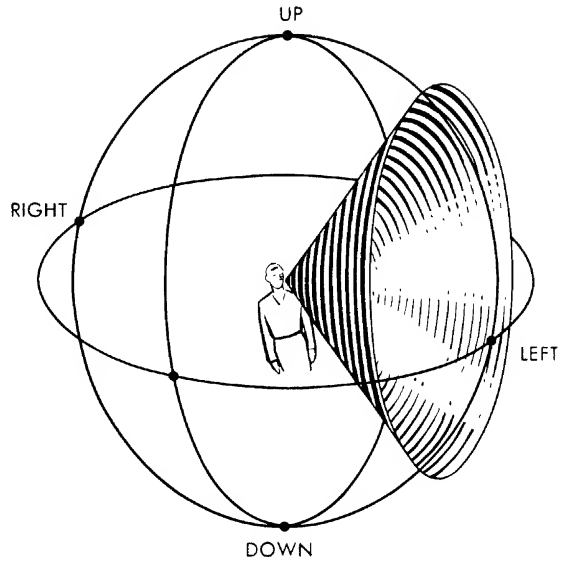


Fig. 11.1. Cone of confusion in auditory localization. Within the area bounded by the cone two acoustic sources may be confused. (E. B. Newman. Hearing. In E. G. Boring, H. Langfeld, & H. P. Weld (Eds.), *Foundations of psychology.* New York: Wiley, 1948.)

toward detecting the angle of elevation of the source. Wallach (1940) found that if he rotated the head and sound source together in the horizontal plane, the sound seemed to come from above. He called attention to the fact that the only sound sources for which horizontal head rotations usually produce no change in binaural phase and intensity relations are those directly above, and possibly directly below, the listener. Thus we can suspect that the location of sound is keyed to these two factors for hearing, no matter how curious the results in special experimental situations turn out to be. If this is so, deprivation of opportunity to learn may preclude the development of even some of the most fundamental features of human apprehension—that is, of the experience of an external space domain.

LOCALIZATION IN THE OPEN AIR. Most of the work done on hearing, whether on localization or on any other aspect, has been conducted in the laboratory, that is, indoors. Nowadays, we have two alternatives to using ordinary rooms with their reverberations that possibly distort results. There are "soundproof" (that is, acoustic-energy absorbing) rooms and there are open-air situations.

Stevens and Newman (1936) set up a tall swivel chair on top of a nine-foot ventilator on the roof of a building. This arrangement provided

unobstructed space in all directions; even the nearest horizontal surfaces were 12 feet below the observer. The acoustic source was mounted on a 12-foot arm connected to the base of the observer's chair; the arm was counterbalanced and could be shifted noiselessly from one position to another around a complete circle. The stimuli produced tones, a hiss, and a click. For the frequencies between 400 and 4,000 cycles, the energy level was 60 decibels. The energy level for frequencies beyond this range in either direction was about 30 decibels.

The observer's task was to distinguish between sounds heard from behind and from in front of the lateral plane—that is, the vertical plane running through the head from ear to ear. It was found that it was very difficult to make the front-back distinction, and so such reversals were not counted as errors in the investigation. The magnitude of the error was determined as the difference between the reported sound direction and either the lateral direction of the source or the corresponding position in the other quadrant, depending upon which was the smaller. For example, if the source was 10° to the right of the straight-ahead position (at 0°), the observer would be considered correct if he reported it 170° (counting clockwise).

Figure 11.2 indicates the mean of the errors made by two trained observers. The errors for sources of low frequency were quite similar, but in the range of 500 to 3,000 cycles they became progressively greater. Above about 4,000 cycles there was an improvement again, so that at 10,000 cycles localization was about as accurate as at 1,000 cycles.

The maximum error, which peaked at about 3,000 cycles, was explained as follows. Low errors at low frequencies were to be expected because of the phase differences in the acoustic waves for the two ears. Phase differences reach their maximum effectiveness at a little over 1,500 cycles. The effectiveness of intensity differences reaching the two ears from a source off to one side increases with frequency. Such an intensity differential sets in below 1,000 cycles and increases rapidly above 3,000 cycles. This would suggest, then, that at 3,000 cycles errors should be at a maximum in magnitude because phase difference is too slight at the point to help much as a factor, and differential intensity as a factor for localization has not yet become great enough to help much.

Figure 11.2 also shows the reversals that were made in the investigation. The frequency range was found to be divided into two quite distinct portions. Above about 3,000 cycles, the errors were about one-third as frequent as expected by chance. For the lower frequencies, the errors were only a little fewer than expected by chance. The effective factor at the higher frequencies was the intensity differential. Phase differences operated for low frequencies. Thus it was concluded that the reduction in reversals was dependent upon the ability to use the intensity differential in the two ears.

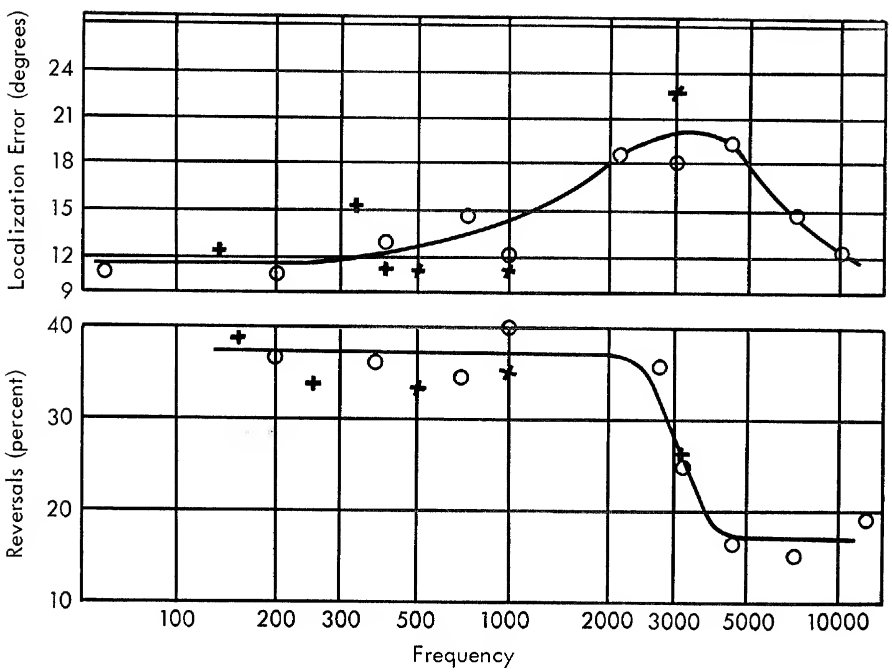


Fig. 11.2. Upper plot indicates the average of errors in degrees of two observers in localizing an acoustic source at various frequencies. The lower plot shows the percentage of confusions between front and rear quadrants. (S. S. Stevens & E. B. Newman. The localization of actual sources of sound. *Amer. J. Psychol.*, 1936, 48, 297–306, Figs. 2, 4.)

When a continuous high-frequency source was swung around the observer's head, he found the tone less intense when the source was behind him than when it was in front. In one part of the investigation, the stimuli were varied in frequency from 3,000 to 7,000 cycles in a random order. This procedure increased the errors of reversal from 18.6 percent in the former procedure to 47 percent. The observers, therefore, must have quite readily developed a personal (or "subjective") standard of intensity in the first procedure.

Hisses and clicks were better localized than tones. It was especially easy to localize the hiss. In fact, it was declared to be almost as definite as if one had been looking at the source. As compared to errors of 16.0° for pure tones, the hiss was only 5.6° and the click was 8.0°. The hiss sounded louder when the source was in front of the observer. Also it sounded like *shh,* whereas when the source was behind the observer it sounded like *sss*. Strangely enough, the intensive and qualitative differences did not rise to awareness in the main part of the investigation. This is a

nice example of how certain factors may be operative below clear awareness but nevertheless considerable in effect.

BINAURAL INTENSITY. One factor aiding the individual to localize sound is the difference in the intensities of the impingements upon the two ears. In general, the sound seems to come from a direction toward the side the more intense the stimulation. This relationship has been studied by various investigators, among them Stewart and Hovda (1913), who used two tuning forks in tandem. The stimuli were led to the two ears by tubes of equal diameter and length. One fork was placed about one centimeter from the end of one tube. The distance of the other fork from the second tube was varied from 0.20 centimeter to 2.20 centimeters. An intensity ratio of 10 to one was needed to shift the apparent direction of the sound source 45°. This ratio is much greater than the one resulting from an acoustic source placed at 45° from the median plane and would thus suggest that intensity is not alone in accounting for the normal accuracy in experiencing the direction of sound sources.

BINAURAL PHASE DIFFERENCE. Acoustic stimuli originating from a common source to one side or the other of the median plane do not reach the two ears at the same time, and when they do reach the two ears they are slightly out of phase. The higher the frequency is, the less the time is involved in the various phases of a given wave. Very high frequencies might well be expected to provide no basis for utilizing phase difference.

Recent investigations have shown that binaural phase difference plays a role but is effective only with pure tonal sources of 1500 cycles per second and below. As was implied, phase difference is reducible to time difference. This was taken advantage of in experiments of Wallach, Newman, and Rosenzweig (1949), in which two click-producing sources, one for each ear, were used. Time differences of as little as 30 to 40 microseconds led to above-chance numbers of reports to one side or another. When the time difference in the click sources was increased to 2 or 3 milliseconds, sound was heard as a double click. With still longer separations, the clicks were heard as fully separate and in widely separate locations.

Reverberation poses certain applications of the principles involved in binaural phase differences. It seems, however, that with click-producing sources, the first stimuli to arrive have precedence over the later ones in determining localization.

STEREOPHONIC LOCALIZATION. Two ears per person and the instrumental facilities of leading into them various acoustic stimuli independently provide tremendous possibilities for manipulation of stimulus conditions. A number of effects quite bizarre to the normal listener have been produced.

The discrepancies between what is heard and what exists in a spatial way in the external environment can be overwhelming, to say the least. The problems consist in (1) manipulating the positions of the sound sources, (2) reproducing the acoustic wave patterns set up at various positions with reference to the sound sources, and (3) leading separate end results to the two ears independently.

For example, a dummy listener (mannequin) can be set up with a microphone at each ear. The wave fronts reaching the two ears will be different for a single acoustic source located asymmetrically to them. If what reaches each ear is recorded on a separate tape or separately on a single tape, the result can be played back to a listener. The listener will wear ear-phones and the two different sound tracks will feed their outputs into the two ears separately. The simplest result would be that the listener would hear a sound coming from off to one side. If two separate sources had been recorded, he would hear two sources located at different points. If the source moved, he would hear it as very definitely moving. The source could have been produced by an object moving toward the dummy. In that case, the listener will hear the object coming toward him and will make the appropriate movements to get out of its way. If the original source is rotated around the dummy's head, the listener will hear sound being moved around his own head.

Nowadays, we have stereophonic recordings of musical compositions, double-track tape recordings of wave fronts picked up from two different positions. The net result is that the listener hears the music as pervading space all about him. Instead of being heard as coming from some single direction in front of him, he hears the music as being everywhere. This effect is the nearest thing in audition to what externality is to the person visually. And it ought to be, for effects from two widely separated positions in space are led to the two ears, separately, rather than having sound come from one restricted direction in space, as it usually does. We pointed out earlier that, through optical means, many points in space are represented on the retina from instant to instant. If vision were utilized by only looking through a narrow tube with one eye, no real notion of space such as we know it would develop. Vision in this restrictedly perceived fashion would be somewhat analogous to the way ordinary hearing, by its very nature, is found to be used.

With stereophonic conditions of hearing, sound takes on its maximal spatial properties for the sighted individual. (The effects of stereophonic hearing in the congenitally blind have either not yet been tried or not reported on in the literature. To test the blind with stereophonic instrumentation would be extremely interesting and possibly very informative.) With stereophonic conditions, one is within the sound field and unable to move in any direction to escape from it or lessen its intensity or otherwise avoid or diminish its intrusion upon him. Like visual space, it becomes an extensional domain, a kind of medium within which the listener exists.

We need not possess stereophonic instruments to experience a moderate amount of this. Much of our auditory experience occurs indoors or in other partially confined spaces rather than in the broad out-of-doors where there are no buildings, hills, or other objects to confine the sound waves and reverberate them. Therefore, although we do not produce separate acoustic wave patterns from two different locations, we do receive with the two ears very complex wave fronts produced by reverberation.

To make this clear, refer to Fig. 11.3, which indicates that, although there is only one original acoustic source (S), the waves strike and are reflected off the walls at various places so that the listener (E) receives acoustic energies from a host of different directions. This adds to the "noisiness" or obtrusiveness of the sound, although the total energy reaching the ears is not any greater than or as great as if he were nearer to the source in the open. In the open, there would be a whole set of directions from which the acoustic waves would not reach the listener, owing to absence of reverberation. Sound would not seem to him to come from all around him and would thus be unobtrusive. He could escape the sound if he cared to.

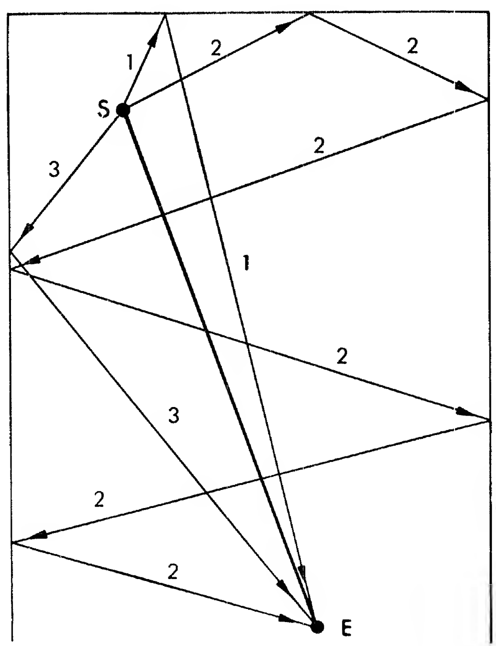


Fig. 11.3. S, the acoustic source, reverberates from walls of a room in addition to supplying energy that reaches the listener (E) directly. Each wave front is numbered.

REVERBERATION AND DISTANCE. There is a relation between the perceived distance of a sound source and the reverberation component in comparison

to the energy that reaches the ear directly from the source. Figure 11.3 would tend to suggest that if a second source were placed closer to the listener than the first source, the major portion of the energy reaching the ear would reach it directly. Only a small amount of energy would reach the ear after being reflected back and forth between the walls. This difference would be represented, then, in the character of the wave fronts reaching the ear. Since the relations between reverberation and distance from the ear are lawful ones, they can be learned. Thus, part of the basis for hearing a tone as originated far away is to be attributed to its reverberation characteristic rather than wholly to its reduced energy content. Another potential spatial characteristic of sound—its distance—is therefore based upon complexity of wave fronts.

FALSE LOCALIZATION. A conclusion easily arrived at is that the localization of sound sources is very poor. Whereas the usual technique of determining human capacity or sensitivity is to set up simplified experimental situations and determine thresholds, one may, on the other hand, examine what happens in unsimplified or everyday situations. Several such unsimplified situations described here are meant to illustrate the basis for concluding that sound fails to have strongly compelling spatial qualities or that perceived localization is always primarily dependent upon acoustic factors. Sighted persons may at times tend to localize sounds and to become disturbed when no satisfactory localization can be made. The congenitally blind may not be similarly impelled. Our supposition is that if the localization of sound is poor in the sighted, it need not exist at all as a medium for experiencing externality in the congenitally blind.

By false localization is meant hearing a sound as originating from one direction and distance quite different from those of the actual source. Ventriloquism, a complex situation worth considering, is, in part, the art of producing sounds that are falsely localized. Our purpose is not to present an exposition on ventriloquism but show by it that localization of sound is quite poor. The illustrations should indicate that there need be nothing very compelling about a set of sound waves to make the perceiver detect the correct direction and distance of their origin.

In the more usual ventriloquistic situation, the ventriloquist converses with a puppet constructed with movable jaws, which he operates. The perceiver experiences listening to two people carrying on a conversation. The words of the puppet are as perceptually realistic as are those of the operator. Since the puppet is in a direction different from the listener, the effect can be described as a false localization of sound when the puppet is perceived to speak.

In other ventriloquistic situations, sounds of the human voice are made to seem to originate at considerable distances from the actual speaker. To do this, the operator must change his voice as ordinarily heard so as to make it seem like a voice coming from a distance. This is sometimes spoken

of as "throwing" the voice. It is actually the changing of the acoustic output as just described and providing a number of visual and other stimulus conditions consistent with the acoustic stimulus produced.

We might generalize as to what is necessary for the success of ventriloquism. The conditions would seem to be: (1) The production of acoustic stimuli at one location and of a character to be heard as coming from another location. This often is accomplished by using two voices from one speaker, one the natural voice and the other a differently sounding one not accompanied by any visual evidences that the real speaker is producing the sound. (2) The production of visual influences that are more potent in localizing the perceived origins of the sound than are the characteristics of the wave fronts as they reach the ear. This is accomplished most easily by use of a puppet, which is visually perceived as a different person. One need not manipulate the distance characteristics of acoustic wave fronts as much as the visual characteristics of the situation. In all cases there must be something definite to be seen at some location or other, so that a localization can be made. The seen object could be a distant puppet or it could be a wall, just beyond which the sound could seem to originate.

False localization need not involve voices. In fact, it may well involve other familiar sound sources with regard to which the listener may be expected to react in characteristic ways. On one occasion, for example, the author pulled alongside the curb in an old Model T Ford to wait for a friend. It was in the days when streets were still quiet, and all that could be heard when he had settled down to wait was a recurrent click at the rate of one every two seconds, pronounced enough to attract his attention and elicit his curiosity. The source of the clicks was quite indefinite except that it seemed to be someplace in the car. When he looked toward the hood, the clicks seemed to come from under it. When he looked down at the floorboards, the clicks came from under them. In general, the clicks sounded like the cooling of some heavy metal object, so he thought they could represent the cooling of the hot engine, but still he was not satisfied of the source. He got out of the car and looked up under the running-board toward the engine and transmission. When he did so, the origin of the clicks was still elusive but perceived as being inside the car. He had no doubt that the sound was produced by the car itself. Failing to localize the specific origin of the clicks, he finally gave up, although when he climbed back into the car the clicks still persisted. He shifted his attention, however, to a couple of children swinging quietly in a porch swing. The houses were set up above the street beyond terraces that rose abruptly from the sidewalk, so the children on the swing were not far away and were above eye level but of course were many times as far away from him as were various parts of the car. When he finally noticed a synchrony between the clicks and the pendular motion of the porch swing, he readily deduced that the clicks were made by the friction of the suspension chains of the swing on the

screw eyes that supported them. He had finally found the true source of the sound, but it was still easy to hear each click originating below the floorboards of the car. He still perceived the sound as originating in an entirely different direction and at a very different distance from the true acoustic source. We could conclude that sound localization is greatly influenced by seen objects rather than more especially by the quality of the sound waves themselves. Visual context is highly effective in localization.

It is to be admitted that click-producing sources are among the least accurately localized sound producers and thus their effects are most easily influenced and manipulated. But the fact that localization of the click was not accomplished by anything the listener did in changing head position in getting out of the car, peering under it, and getting back in indicates how lacking intrinsic spatiality is the process of hearing, at least on some occasions. Vision is never deficient in anything like the same way or to the same extent. Sound can seem to come from almost anywhere and at times even from nowhere in particular.

Facial vision in auditory perception

Dallenbach, with his colleagues Supa, Worchel, Cotyzin and Ammons, (1944, 1947, 1950, 1953), studied what has been commonly called *facial vision.* They conducted a number of ingenious experiments indoors and found that (1) audition is the necessary and sufficient condition for the blind person's detection and avoidance of obstacles, (2) that pitch is the feature of audition that is involved, and (3) that frequencies of 10,000 cycles are necessary for the performance. From these factors it was deduced that anyone who—whether blind or merely blindfolded—possesses normal hearing should be able to learn to detect and avoid obstacles. This took much of the mystery out of facial vision as expressed by some earlier students of the phenomenon. For example, Diderot had called facial vision an amazing ability possessed by only a few of the blind.

Ammons, Worchel, and Dallenbach (1953) addressed themselves to the question of whether the extensive indoor studies at Cornell University on facial vision could be duplicated outdoors under conditions more closely simulating those in which the blind perform in everyday life. A second question had to do with finding out whether blindfolded sighted persons could learn the ability to perceive obstacles.

Their first experiment consisted in determining whether blindfolded subjects with normal or near-normal hearing (Group A) could learn to perceive obstacles outdoors and whether this type of subject could learn even with his ears stopped (group B). Both groups of subjects had initial trouble staying on the sidewalk without guidance. Collisions with obstacles were of three kinds: (1) collisions before reporting perception of an obstacle, (2) collisions made after having reported the perception of an

obstacle but before being finally sure; (3) collisions made during the time the subject was making final appraisal and was "inching up" to the obstacle.

The subjects of both groups were unable to learn as quickly as subjects in the indoor experiments and their ultimate perceptions were more variable. Perception of obstacles was influenced by wind, sun, and clouds. For example, when walking into the wind, detection of an obstacle was based on the drop in pressure as the obstacle shielded the subject. When walking with the wind, subjects signaled obstacles by reflection of wind from them. Where there was no wind behavior based on such factors of course suffered. When the sun was hot, the presence of obstacles was signaled by temperature changes. Sun shining on various materials caused them to give off detected odors. The net result of the experiment was to show that not only the blindfolded but also subjects with the additional deprivation of a certain amount of hearing could learn to detect obstacles out of doors by means undetermined.

The following experiments were made to determine the kinds of factor used by the subjects in detecting obstacles in the first experiment. The general conclusions derived from the whole group of experiments were that (1) blindfolded and blindfolded and ear-stopped subjects could learn to detect obstacles, (2) the behavior of the latter subjects differed from the behavior of the subjects blindfolded only, and (3) no single stimulus condition is necessary for obstacle detection. Audition is the principle basis for detection but is "necessary" only in the sense that it is the most reliable and universal of all the factors used. A number of corollaries to these three conclusions were also stated. For example, the "black curtain" or "dark shades" mentioned by some subjects upon approaching an obstacle were taken to be imaginal experiences evoked associatedly by auditory stimuli. Subjects helped or hindered by the nighttime experiments fell into groups. Subjects whose performances were bettered were still able to use certain auditory cues when their ears were stopped and thus sought no others. Subjects whose performances were impaired sought other factors when, under the conditions of experimentation, the auditory factors were not usable because of the ear blocks. The thermal and olfactory impingements served them well enough in the sunshine but failed them at night because absent.

We can see, in the general type of performance just described, what many would call a form of space perception. For us it is another example of the sequential or bit-by-bit sort of perception that enables people to get about in space. Once an obstacle is detected, the next thing to do is move alternately to the right or left so as to determine whether the signals from the obstacle diminish. With this type of feedback, the skilled person can steer himself around the obstacle almost as if he "saw" it. Of course, varying degrees of skill are to be expected.

Facial vision, then, is another example of the piecemeal detection of

the structure of space rather than the apprehension of space as a domain, that is, true space perception. Facial vision could naturally be expected to be more or differently effective in the adventitiously blinded than in the congenitally blind.

Matching auditory and visual perspectives

The other side of the story of sound localization lies in findings made by acoustic engineers in matching picture strips and sound strips for sound movies. It is possible to mismatch these strips in such ways as to produce the perception of a person talking with the sound originating at some distant point. In one way this is an example of a *ventriloquistic situation* such as we have already described. In another way it shows that the quality of a sound and its perceived distance go hand in hand. If this interrelation was an extremely rigid and sensitive one, the argument for the relative spatial indeterminateness of sound would be negated.

The curious thing about mismatching sound and picture strips on a movie film is that little can be done to bring the phenomenal location of sounds any closer to the listener than the actual acoustic source, generally placed right behind the projection screen. On the other hand, mismatchings that induce hearing sounds as farther away than the visual source can manipulate phenomenal distance quite considerably.

It may be useful to know how sound and picture strips are properly matched. By experimentation it has been discovered that to equate sound with picture involves the focal length of the camera lens, the relative distance of the microphone from the acoustic source to the camera, and the reverberatory properties of the walls of the room in which the movies are made. Cameras with long-focal-length lenses bring distance scenes up close. Microphones quite near the acoustic sources produce stimulus end results perceived as objects near by. If the walls of the room are highly reverberatory (or live), the percentage of the distance from the acoustic source to the camera at which the microphone must be placed has to be reduced in order to cut down the reverberatory component picked up by the microphone, even though the total energy content is increased. The total energy content is not as influential as a stimulus factor for determining perceived distance as is the reverberatory content. The relation between the three factors just mentioned is given in Fig. 11.4.

Sounds as symbols

Sounds do not refer as directly to objects as visual experiences do. Sounds are often of more significance to the human being as symbols than as indications of the existence and location of objects at the moment. Sounds can be used independently of the reference to the world that per-

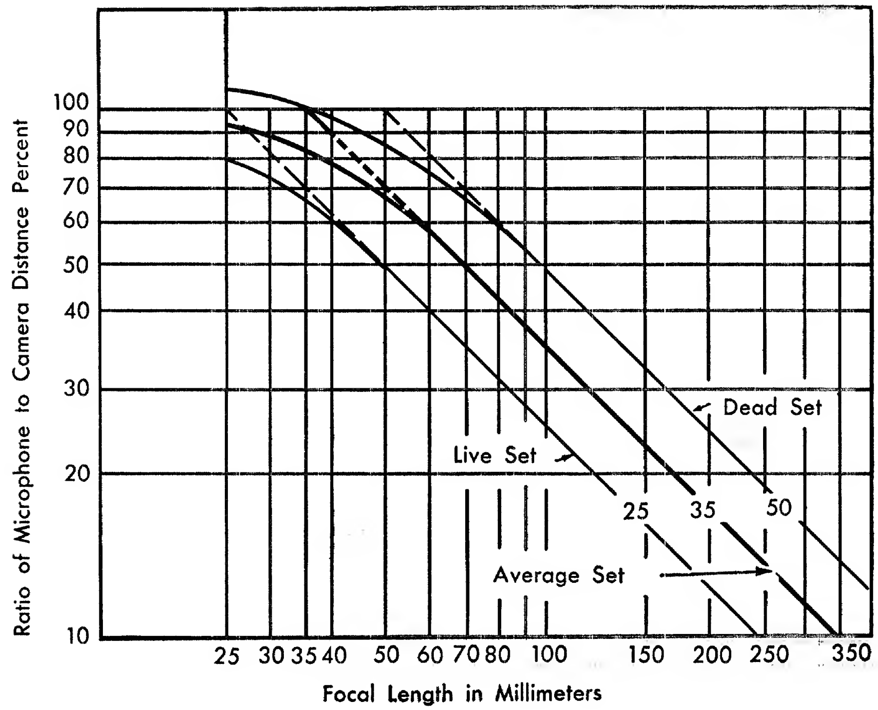


Fig. 11.4. Distances from a photographed object (such as a person speaking) that a microphone should be placed, depending upon the focal length of the camera lens. The center curve is for a lens of 35-millimeter focal length. Assuming that the pickup is appropriate for this lens when the microphone is at camera distance, the microphone must be placed at other distances from the sound source for lenses of other focal lengths. If the focal length is greater than 35 millimeters, this distance is some percentage of the camera distance. The other curves are for sets (stages or scenes) where the sound absorption is either greater or less than average; for these, lenses of 25 and 50 millimeters may be used as reference instead of a 35-millimeter lens. (After J. P. Maxfield. Some physical factors affecting illusion in sound motion pictures. *J. acoust. Soc. Amer.*, 1931, **3**, 69–80, Figs. 1, 4, 5.)

ception relates to the person at a given moment. That is, they can be used to convey ideas that may be independent of the momentary space field and temporal movement. This is not common for most visual objects.[6] Al-

[6] The sounds meant here are sounds heard as words. Obviously words are not exclusively auditory, for we have written as well as spoken language. Even so, the auditory use of words is involved in verbal imagery. Hence, it is perfectly legitimate to deal with words as sounds in such cases as we are dealing with here.

though one may convey ideas by pantomime, it is not often done nor nearly so accurately and easily accomplished. Curiously enough, the communication of ideas by *signs* is called sign language. In broad principle acoustic as well as photic sources of stimulation are signs.

In this connection it is relevant to point out that the synesthete is a person who uses visual items as symbols in a manner somewhat similar to the way that sighted nonsynesthetes use sounds (that is, words). The blind synesthete as described by Cutsforth (1951) uses visual experiences (or imagery) induced by acoustic stimuli for his thinking processes. They are his language, although they are visual items other than written words. We are not certain as to the role and conditions of operation of synesthesia in the sighted person, but we can make some suppositions. For example, let us suppose that for a given sighted individual visual items rather than auditory items (words) are the symbols for his language. He would thus employ vision for his thinking in the way that the normal sighted person uses words. The sighted person must use vision to get around in his world; he makes all kinds of visuomotor manipulations from moment to moment. If he had to use the visual modality for his thinking also, he would be forced into a double use of vision and thus into conflict. He could not well use vision for perceptual purposes relating to space and time concurrently with purposes divorced from time and space. He would have to stop and close his eyes in order to think. Otherwise, what he would need to "see" would not refer to what is taken to be out in front of him, and yet at the same time he would need to refer quite directly to those very realities—the objects of space and their locations, sizes, and shapes. This difficulty is inherent in a small way when formalized movements such as those in ballet are to be taken as meaning what they do not literally mean when functioning merely as direct perceptions of people moving about on a stage.

We can say in conclusion, then, that although it seems in keeping with observations to disclaim any initiating role for audition in the production of perceptual externality, we can conceive for audition the prime role in dealing with abstract ideas. Hearing is divorced from spatial realities, or from dealing directly and inescapably with the space domain, greatly enough that it can be used for abstract symbolism. Hearing is so space-free that it can play the role it does. Hearing gives us a mechanism that at one and the same time involves sensory processes with their means of transfer, or signaling, between persons, and a relatively space-free tool for abstract symbolism in the parties involved. Vision could not carry on this function as well.

SPEECH PERCEPTION

In recent years, speech perception has become of such wide-spread experimental interest that we shall devote some attention to it here. Al-

though speech is first of all an acoustic affair, it is not exclusively so; lip-reading attests to the fact that speaking can be seen as well as heard. But since we are dealing with audition, we shall confine our attention to the acoustic part of speech.

Since sounds that are heard as speech and sounds that are not heard as speech are dealt with very differently by the listener, it is easy for descriptions of what is called the stimulus to become contaminated by descriptions of the listener's response itself. This is not a new problem for we have met it at every turn in the discussion of previous forms of perception, but it does involve much more complex ramifications than any case met so far.

Articulation

We immediately meet with the term *articulation*. Sometimes an acoustic product that is heard as speech is called an articulation because the perceiver hears it as something distinctive. On the other hand, *articulation* is used to describe the vocal processes whereby distinctive acoustic results accrue so as to be heard as speech.

Speech, then, is a form of acoustical input utilized by the auditory system. It is fundamentally a form of energy made to impinge on the ear. However, a description of the acoustic input, stated simply in terms of wave frequency and amplitude (the usual energistic description) is not in itself meaningful for purposes at hand. There must be an additional description of what actually occurs before the stimulus can be appropriately delineated. And this delineation has to do with the category of patterning called *articulation*.

Speech is a two-way affair. It is produced by the human organism as well as perceived by other humans. As the behavior of a vocal mechanism, then, articulation is viewable from two aspects: the motor mechanisms involved and the acoustic vibrations produced. The task for the researcher in speech perception is thus to discover what goes on in the production of what is heard as speech sounds. The necessary vocabulary is thus a reflection of how the acoustics of speech is produced as a description of the product.

To the layman, the units of speech, are letters, syllables, and words, particularly words. But to those who study speech experimentally in a fundamentally scientific way, speech is broken into units finer than words, and the various pronunciations of letters become a matter to consider.

Since speech is an acoustical product, it can be copied, modified, stored, and imitated by mechanical and electrical means. With the aid of recorded pictures of the wave patterns accomplished by the use of present-day instrumentation, anyone is able today not only to hear something that has been said but to view the stimulus or the wave pattern of the acoustical

product. Such records are subject to analysis to determine their characteristic components and to determine whether what is heard relates in a constant way to these components or whether human perception displays certain unexpected variants in relation to acoustic patterns. It is thinkable from the very start that some features of the recorded wave picture may be more dominant than others or more inflexible in their effect than others in producing the perceptual end result. It is also thinkable that the components play very different roles in various sequences.

Speech described solely in acoustical terms would pertain only to the wave patterns as evidenced by instruments sensitive to acoustical energy. This would not in itself tell anything about how these complex wave patterns are produced, nor would it be a statement of the relation of wave patterns to the letters or words that form what we call language. The study of speech perception thus has to develop this relation by employing *phonetics*, the branch of linguistics dealing with the sounds of speech. It includes *articulatory phonetics*, which studies the physiological processes involved in speech production as well as the distinctive sounds that are heard.

Phonetic alphabets

Phonetic alphabets are not familiar to most people; they have arisen to aid students of various languages transliterate alphabets into a standard notation, necessary because certain letters (if not all of them) from language to language and even within the same language have more than one pronunciation. (See Table 1.) For example, the vowel *a* in English is pronounced differently in the words *bathe*, *bath*, and *haunt*. Most vowels have a long and a short pronunciation, and some have others. A phonetic alphabet lists, by use of symbols, the various pronunciations (or sounds) of the

Table 1. Some Phonetic Symbols

PHONETIC	DICTIONARY	KEY WORDS
f	f	*f*ig, i*f*
θ	th	*th*ick, ba*th*
s	s	*s*ew, ba*ss*
ʃ	sh	*s*ure, ra*sh*
tʃ	ch	*ch*ick, lat*ch*
v	v	*v*ow, lea*v*e
ɚ	th	*th*is, la*the*
z	z	*z*ing, lo*s*e
ʒ	zh	le*s*ion, mea*s*ure
dʒ	j	*j*ab, hedge
ŋ	ng	sti*ng*, wro*ng*
ə	ô	border, l*aw*

various letters and letter-combinations of the usual alphabet. A phonetic alphabet, therefore, is useful material in studying the perception of speech.

A second form of material is the classification that describes the way certain sounds are produced by the vocal apparatus—that is, *labials, dentals, nasals, palatals,* and so on.

A third form of material has to do with the temporal and intensive characteristics of articulations, such as stops, fricatives, and affricates. A *stop* is the acoustic effect produced by the complete momentary blockage of the breath stream (or implosion), as with the lips or tongue, followed by a sudden release (a "plosive," as in contrast to a "continuant"). In English, the stops are *p, b, t, d, k,* and *g;* the nasals *m* and *n* may also be included. A *fricative* is a consonant produced by the passage of breath through a narrow aperture with a consequent audible friction such as *s*. An *affricate* is an acoustic effect consisting of a stop followed by a fricative release at the point of contact.

A way other than alphabets of talking about the material perceived as speech is to define another unit, the *phone;* defined either in terms of (1) articulatory processes or (2) acoustic attributes. Classification of phones involves *phonemes, allophones,* and the like. A phoneme is a class of phonetically similar phones that substitute for each other according to the phonetic environment. A phoneme is the smallest contrasting unit in the acoustic system of language acting to distinguish utterances from each other. For example, the English phonemes *t* and *p* distinguish the words *tin* and *pin,* whereas the qualities of *t* in *top, stop,* and *pit* do not function in this manner and hence are all members of the same phoneme. An allophone is any of the nondistinguishing variants of a phoneme occurring in a particular context. For example, *k* of *coop* and *k* of *keep* are allophones of the phoneme *k*. An allophone is sometimes called a positional variant.

Another basic unit is the *morpheme* with its variant forms called *allomorphs.* A morpheme is the smallest meaningful unit in a language or a dialect. It is sometimes a word, sometimes a base, and at other times a prefix or a suffix. For example, *boy, egg, pro, -ing,* and *-ess* are morphemes.

VOWELS AND CONSONANTS. The study of speech perception recognizes the familiar two-division classification of alphabet letters as consonants and vowels, which are different, both as acoustic stimuli and as something that is heard.

Consonants are divided into three classes according to articulatory criteria (Liberman, 1957) rather than on a strictly acoustical basis:

1. Acoustic effects produced by the consonant constriction are fricatives such as /f, s, u, z/ and the bursts of the stops /p, b, t, d, k, g/. The constriction sounds are produced only during or just after the most nearly closed part of the articulation of the consonant.

2. Acoustic effects originating from action in the voice-box rather than

at the point of consonant constriction. These actions must travel through the entire vocal tract before the result issues from the lips. Unlike the acoustic effects produced by constriction, these are affected by the articulatory movement involved in going from a consonant to the next phone. The first class involves *constrictions;* the second class has to do with *transitions.*

3. Acoustic effects that result from the on-off action of a *fixed resonator.* The nose is a fixed resonator and so nasal resonance is the acoustic feature of the nasal components /m, n, ng/.

FORMANTS AND TRANSITIONS. A *formant,* in acoustics and phonetics, is any of the acoustic vibration frequency ranges in which the partials of a vowel are strongest and determine its "acoustic quality" or "tone color." A partial in acoustics is a simple component of the combination of frequencies produced by the complex vibration of the acoustic source. Partials are either fundamentals or overtones.

Transitions are the acoustical phenomena produced in passing from consonants to vowels and *vice versa.* The perceptual effectiveness of the features involved in transitions are so important that it is difficult to exaggerate their significance.

Recording and playback instruments

Various instruments are used to record the acoustic outputs of speech (Pulgram, 1959). We shall describe only briefly the spectrogram, one kind of record that makes visible the essential features of acoustic output, picturing the characteristics of vowels and consonants and the transitions from one to the other.

Spectrograms as actually recorded are complex patterns of waves representing the vibration frequencies in the acoustic output of speech (Borst, 1956). They are then transformed and simplified into hand-drawn schematics. It is these simplified forms that we shall be primarily concerned with. No waves are evident in them; instead what is painted are two or more broad solid bands representing the frequency locations and amplitude coverages of the original spectrograms (Fig. 11.5).

The ordinate, or vertical, axis of the spectrogram indicates vibration frequencies of a vocal utterance. The horizontal axis represents time. A hand-painted spectrogram consists mainly of broad lines running from left to right in either a straight or a sinuous fashion. Among the briefest spectrograms are those picturing consonant-vowel combinations such as *bi, ba, bo, di, da, do, go.* In Fig. 11.5 there there are two lines or bands for each consonant-vowel combination. The lower band represents the *first formant,* the upper band the *second formant.* Some spectrograms show a *third formant.* (A formant, it will be recalled, is a frequency range in which the partial or component frequencies of the overall output are strongest.)

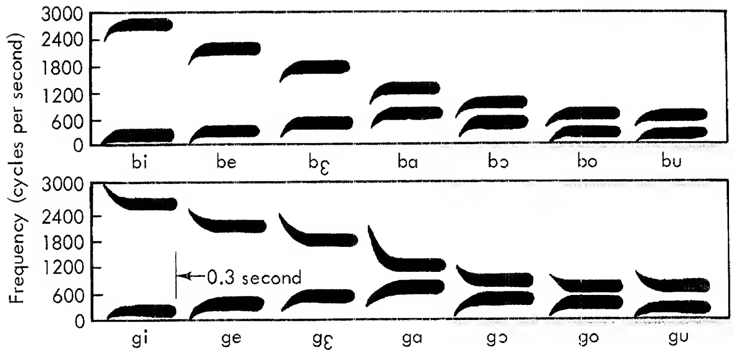


Fig. 11.5. Simplified spectrograms of several consonant-vowel combinations. (P. C. Delattre, A. M. Liberman, & F. S. Cooper. Acoustic loci and transitional cues for consonants. *J. acoust. Soc. Amer.*, 1955, **27**, 769–773, Fig. 1.)

It will also be noted in the figure that the bands begin at single points and spread quickly into band widths. The beginnings of the bands thus represent what we have already defined as one class of consonants, the stops (called stops because the air stream is momentarily obstructed). It is also evident that the formants for one consonant linked with each of several vowels are different and that the transitions are likewise different.

Another instrument in speech study is a device whereby a spectrogram can be used to produce an acoustic output, providing a playback. This instrument can utilize synthetic spectrograms or actual spectrograms that have been altered in certain ways to determine the effects of omissions or variations in the features already discussed. For example, a portion of the spectrogram representing the *b* part of *bi* can be spliced onto a portion representing an *a*. The consequent spectrogram is not heard as *ba* but instead is totally unrecognizable. In general, this procedure has one of two possible results: The result is either unrecognizable or the consonant becomes another consonant.

Speech study by such instruments thus becomes the analysis of the various components in the acoustic records to see how they function in providing the listener with the information found in spoken language. Some parts of the acoustic output are critical and emphatic for this purpose, others not nearly so much so.

Some findings in speech perception

Liberman, Delattre, and Cooper (1952) made experimental modifications in spectrographic displays and played them back as acoustic stimuli. They found that they could produce reasonably intelligible sentences from greatly simplified spectrograms, affording a basis for additional study into stimulus essentials for individual units, whether phonemes, syllables, or

words. They demonstrated that the irreducible acoustic stimulus is the pattern corresponding to the consonant-vowel syllable.

Liberman *et al.* (1956) found among their other results that the transition tempo is enough to distinguish the stop consonant *b* from that semivowel *w* in connection with a number of vowels. The two factors considered in transition are rate and duration. The various vowels tested with regard to rate are not nearly so similar as when tested for duration. They concluded that duration was the potent factor of transition they had been calling tempo.

Liberman *et al.* (1961) measured various durations of silence involved within a speech sequence in which the variable elicited a phonemic distinction. When the same variable was used in a nonspeech acoustic output, no distinctions were found. In the speech example, the duration of silence divided two syllables of a synthesized word: The word heard was *rabid* when the silence was short and *rapid* when the silence was long. With acoustic factors equal, discrimination was more acute between *b* and *p*—that is in *crossing* the phoneme boundary—than *within* either phoneme category. This tallied with the extreme assumption that listeners could hear these inputs only as phonemes, not discriminating any other differences between them.

With the nonspeech presentations, although the same durations of silence separated two acoustic bursts, matching the onset, duration, and offset characteristics of the speech signals, discrimination did not show any appreciable increase in the region analogous to the phoneme boundary. The discrimination of nonspeech inputs was also poorer than that of speech.

Assuming that the responses obtained with the nonspeech inputs represent the basic discriminability of periods of silence not influenced by linguistic training, it was supposed that the peaks of discrimination in the responses to speech inputs stem from learning in perception. Learning was believed to serve to increase discrimination *across* phoneme boundaries.

O'Connor *et al.* (1957) found that the direction and extent of second-formant transitions are potent factors for the listener in distinguishing with stop (*p*, *t*) and nasal (*m*, *n*) consonants. The same variables likewise operate in other consonant groups such as *w*, *j*, *r*, and *l*. Second-formant transitions are to some extent influenced by transitions of the third formant. First-formant transitions also help to distinguish among the stops, nasals, liquids, and semivowels. A liquid consonant (*l*, *r*) is formed without the usual friction in the vocal apparatus, making the consonant somewhat vowel-like. A semivowel is a vowel-like sound, such as *y*, *w*, and *r*, used as a consonant; these are also called *glides*.

Variations in duration and direction of second- and third-formant transitions provide for the perception of various consonants depending upon the place (the frequency level) of production. Such variations in the first formant provide for the hearing of manner.

There are typical loci at which formant transitions begin or to which they are assumed to point. Transitions are thus movements of formants from their loci to frequency levels appropriate for the phone that follows (Delattre, Liberman, and Cooper, 1955).

Proprioceptive elements in speech perception

Liberman (1957) pointed out that the correspondence between articulation (a motor aspect of speech production) and the acoustic effect is not always one to one. When articulation and the acoustic effects "go their separate ways" (do not correspond), it may be asked which way the perception goes. Liberman says that the perception goes with the articulation.

Figure 11.6 shows the various transitions in the second formant of *d* and *g* needed to precede each of several vowels. In the case of *d*, the direction and extent of the second formant changes with the vowel involved.

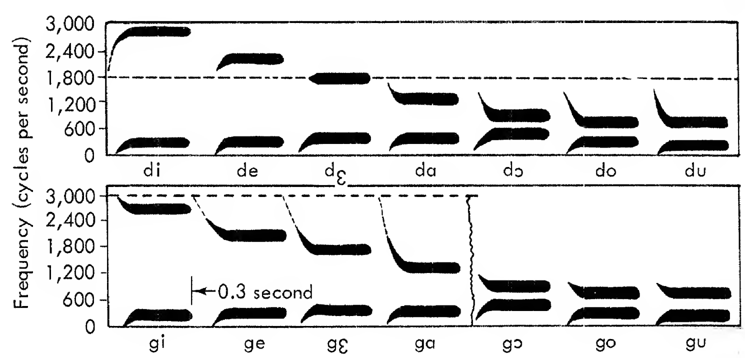


Fig. 11.6. Simplified spectrograms representing the relation of various acoustic and articulation effects. (A. M. Liberman. Results of research on speech perception. *J. acoust. Soc. Amer.*, 1957, **29**, 117–123, Fig. 3.)

Despite this, the perception of the consonant is always the same; the listener always hears *d*. The one feature of the acoustic basis for *d* that is constant in all cases is the locus of the *d* transitions for the various vowels; they all seem to originate from the same frequency, 1800 cycles per second.

The situation is different for *g*. The consonant makes a larger transition to the vowel as the vowels are varied from *i* to *a*. The locus, however, is always around 3000 cycles per second for some of the vowels. But for *go* it suddenly changes. This means that acoustically there is a real discontinuity in the acoustic product. Liberman states that he has not been able to find anything in acoustics by which to explain why *g* always sounds like *g* despite this sudden shift of locus.

This example and others suggest to Liberman that speech is perceived in reference to articulation. He suggests that articulatory movements and

their sensory results mediate between the acoustic input and the end result called perception. In the extreme and traditional form of this view, it is supposed that we overtly mimic the incoming speech sounds and then react to the proprioceptive and tactile stimuli that are produced of such articulatory movements. Liberman says that while this position is totally untenable he believes the reference to articulatory movements and their sensory results must somehow take place in the brain without passing into the peripheral mechanisms. The question in connection with speech learning is not whether learning occurs but how it occurs. The answer seems to be that what is learned is a connection between acoustic inputs and certain articulatory processes in the listener.

A theory of speech perception

Liberman *et al.* (1962) have suggested a theory of speech perception based upon a number of facts and requirements, the first of which is that the elements of a phonemic system must be identifiable in absolute terms. This means not that identification is perfect and the listener will make no mistake but that he will hear one phoneme or another at a given instant and not some sort of an intermediate sound. For instance, the phoneme *b* must be heard as *b*, not as merely something more or less like *b* than the last sound heard. A second requirement is that the phoneme must be heard quickly; whatever the biological machinery required, it must accomplish its task quickly, although we do know that at times recognition is delayed.

The distinctiveness manifested in speech perception is not inherent in the acoustic input itself, as is shown by the kinds of responses obtained in the comparing speech and nonspeech inputs. Acuteness in discrimination is shown only in response to the inputs heard as speech. The distinctiveness of response emerges at phoneme boundaries in spite of the fact that the acoustic signals (or inputs) for the stop consonants lie on a continuum. This poses the question of whether these peaks of discrimination are an inherent feature of the perceptual machinery or whether they are the result of learning. The answer at present seems to assign the responsibility to learning.

An examination of the way learning takes place has led to the belief that the articulatory mechanisms—motor mechanisms of the vocal apparatus—are involved and are a definitive factor in making the response to speech signals uniquely effective. It is recognized that response to speech inputs is quick. Hence, all incoming signals cannot be "tried out" by articulatory mimicking before speech recognition actually results. Liberman and his colleagues, calling their theory a motor theory, attempt to conceive of a way in which the central nervous system itself can function to obviate this and act in accord with the learning brought about by the feedback

from the vocal machinery on previous occasions. It is apparent that this requirement is not yet well accomplished, for it is a most subtle task.

These theorists do try to take advantage of experimental evidence such as, for example, the fact that the correspondence between phonemes and articulation is more nearly one to one than that between phonemes and acoustic inputs themselves. That is, when articulatory "matching" responses are made by trying to mimic the sounds heard, the neural feedback from the articulatory movements is more distinctive than the acoustic inputs themselves.

Liberman and his co-workers recognize a distinction between articulators (vocal mechanisms) and the neural commands needed to activate them. So they attempt to conceive of how the brain uses the results of learning without the use of actual articulation itself in the listening process. It is much more difficult than to conceive of how articulation by way of mimicking is brought into learning to sharpen the acuteness of speech production as trial and error proceeds. The problem here is not wholly unlike the problem posed in social perception in explaining the perceiver's ability to discriminate tabooed items from socially acceptable ones and to manifest a higher threshold for the one class of items than the other. It seems fortunate, however, that the authors have seen fit to try to take into account the motor system in perceptual response.

SUMMARY

Whereas the previous chapter dealt with the fundamental features of hearing, the present chapter has dealt with such topics as the externalization of the sound experience, auditory localization (where sound seems to come from), the relation of reverberation to perceived distance, the matching of auditory and visual perspective such as is used in sound motion pictures, and the role sounds play as abstract symbols or words.

The second part of the chapter dealt with the perception of speech. The concepts and procedures that investigators of speech perception have devised to deal with speech were discussed. This discussion began by describing how vowel and consonant sounds are produced by the human speech mechanism. The process of articulation whereby a sound is heard as a speech sound was also included. A brief description of nasals, dentals, palatals, and the like was given. Various experiments were described that give some insight into the tasks and problems that the investigator of speech perception faces.

5

TWELVE

The Senses of the Skin

⁂ The investigation of the cutaneous senses has involved a number of categories of study that follow somewhat the criteria mentioned earlier for isolating and establishing the existence of different sense modalities. Thus one type of study concerns itself with the kinds, amounts, and modes of application of stimulus energies. Another focuses on skin and deeper tissue structure, to identify and organs and even nonneural tissue characteristics to relate anatomical findings with sensory end results. Another type of study identifies diameters of conducting nerve fibers, for nerve fibers in accord with size are known to have different thresholds and conduction rates. Certain intimate kinships between the classical sense qualities are sometimes identified in this way. Still another type of study concentrates upon tracing the neural pathways to the brain, since these pathways are interrupted at successive synaptic junctures where spatial summation, facilitation, reflex activity, or other actions become involved in the overall activity complex.

All these forms of endeavor are required to account for the nature and interrelations of the skin senses, for certain categories of data taken alone provide for misleading interpretations.

THE STRUCTURE OF THE SKIN

The skin has more or less arbitrarily been divided into three layers: the *epidermis*, the *dermis* or corium, and the *subcutaneous tissue*. Each is far more complicated structurally than the average person would suppose and extended description of them would only emphasize their complexity.

The specialized sensitive structures in the skin may be divided into

three classes: (1) *free nerve endings*, branching nerve fibers that end upon epithelial cells; (2) *hair follicles*, whose bases are supplied with nerve endings; and (3) *encapsulated end organs* of various types, in which the nerve fiber ends within a shell-like structure, of which there are several types. Encapsulated end organs differ greatly in size and structure and consequently have been classified and named. Best known are the Meissner corpuscle, Pacinian corpuscle, Ruffini cylinder, Krause end bulb, and Golgi tendon organ and Merkel's cells. Some doubt exists as to how clear cut the distinctions implied in the naming of some of the structures can be.

In the early decades of the study of skin sensitivity there was an attempt to relate forms of sensitivity to specific structures. It appeared that tactile sensitivity was mediated by Meissner corpuscles, since it at first seemed that these structures were frequently seen in body regions where tactile sensitivity was at its greatest. On the same basis, Krause end bulbs were identified with sensitivity to low temperatures and Ruffini cylinders were identified with high temperature sensitivity. Free nerve endings were most frequently identified with pain experiences.

These earlier identifications were made on a gross basis. Later studies involved more precise attempts to connect structure and function. Studies using carefully controlled sensory data and slices of skin (biopsies) for examination of the structures actually present in the localized skin region stimulated have led to the conclusion that no fixed relation between particular types of encapsulated end organs and sensory experience can as yet be stated. There is often no encapsulated end organ found in the biopsy of a sensitive spot determined by stimulation.

What is known as the Oxford group interprets the findings as follows. Different cutaneous experiences (perceptions) are produced not as a result of selective activation of special receptors but as a result of different impingements affecting given neural elements in a different way. Thus the internal neural elements in the pathway from skin to central nervous system produce different discharge patterns, rather than there being a selective effect among them whereby some discharge and others do not, to provide the various sensations of cold, warmth, pain, and touch-pressure.

The basis for this conclusion is that experimenters are unable to relate specific neural endings with specific modalities of experience. In fact, all modalities of experience have been elicited from the cornea of the eye in which the only known ending is the simple *free nerve ending*. The Oxford group says that careful histological evidence shows that all the specialized endings are essentially alike, for they arborize into the same fine filaments. The evidence shows that there is a range of intermediate structures extensive enough not to believe in the classification of specialized structures of the types generally found in the literature. This would mean that, as far as the sense organ goes, there would be no such thing as four sense modalities.

The separateness of modalities would arise first as separate neural *pathways* from the skin leading to different projection areas of the cerebral cortex.

Not all workers seem willing to interpret the findings in quite the way just indicated, however. Some credence still is retained in the significance of the diversity of structure as a condition for difference in sensory experience that results.

One view proposed some time ago by Head (1920) was that there are two kinds of sensations as a result of a dual sensory mechanism in the skin. One is a more generalized and more primitive system; this he called the *protopathic system.* The other is a more specific and more advanced one, called the *epicritic system.* This idea did not gain general acceptance, though it did gain considerable attention. Even so, some workers think there is a possibility that a protopathic system may exist, since the activity set up by tactile stimuli, for example, is conducted up the spinal cord in at least two independent pathways. For a more extensive discussion of the topic see Bishop (1946) and Rose and Mountcastle (1959).

NEURAL PATHWAYS FOR THE SKIN SENSES

Nerve impulses from the touch sense are carried by myelinated and nonmyelinated fibers entering the dorsal aspect of the spinal cord. Some of the fibers synapse and the pathway crosses to the opposite side of the cord and ascends to the thalamus and thence to the cerebral cortex. The tracts to the thalamus are called the spinothalamic tracts (Fig. 12.1). Another pathway for touch ascends on the same rather than the opposite side of the cord through the *posterior funiculus.* At the level of the medulla, two nuclei are involved, the *nucleus cuneatus* and *nucleus gracilis.* At this level, the double pathway crosses and ascends as the pathway called *medial lemniscus.* After this crossing, the double pathway joins and accompanies the *anterior spinothalamic tract* that had been formed by fibers that had already crossed at the spinal level. As the medial lemniscus ascends, it is joined by tactile fibers from the head and face after the pathway synapsed at the trigeminal nucleus. The import of the process is that at various levels in the trunk and the face and head, touch fibers enter the cord and brain stem respectively and cross over to the opposite side before reaching the cerebral cortex. The pathways are separate from other pathways and thus satisfy the appropriate criterion in the four that have to do with isolating sense modalities.

We now come to describing the pathways for the other skin senses. The impulses resulting from pain-producing impingements also involve both myelinated and nonmyelinated fibers. Some of the fibers, like some in the touch pathway, form reflex connections in the cord. Others synapse in the dorsal gray matter. The postsynaptic fibers ascend in the cord

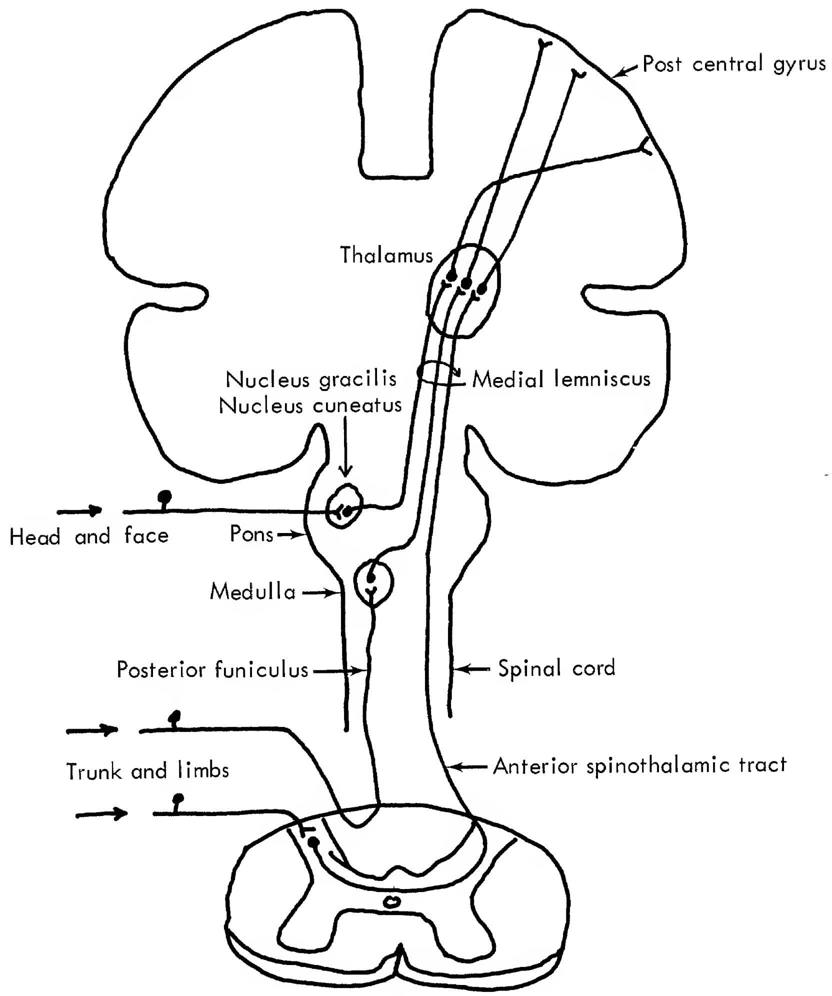


Fig. 12.1. Neural pathways for the tactual sense.

through the lateral funiculi as the *lateral spinothalamic tract* (Fig. 12.2). These fibers are joined as they ascend by fibers coming from head and face by way of the *trigeminal nerve.* The fibers entering the brain stem from the trigeminal nerve descend a short way and then synapse. The postsynaptic fibers cross and join these fibers ascending from the trunk and hind limbs. The pain pathway ascends to the thalamus and from there to the *post-central gyrus* of the parietal lobe. The pain pathway in the cord is entirely crossed, whereas in the touch sense the pathway is double, one part crossed, the other uncrossed until it reached the brain stem.

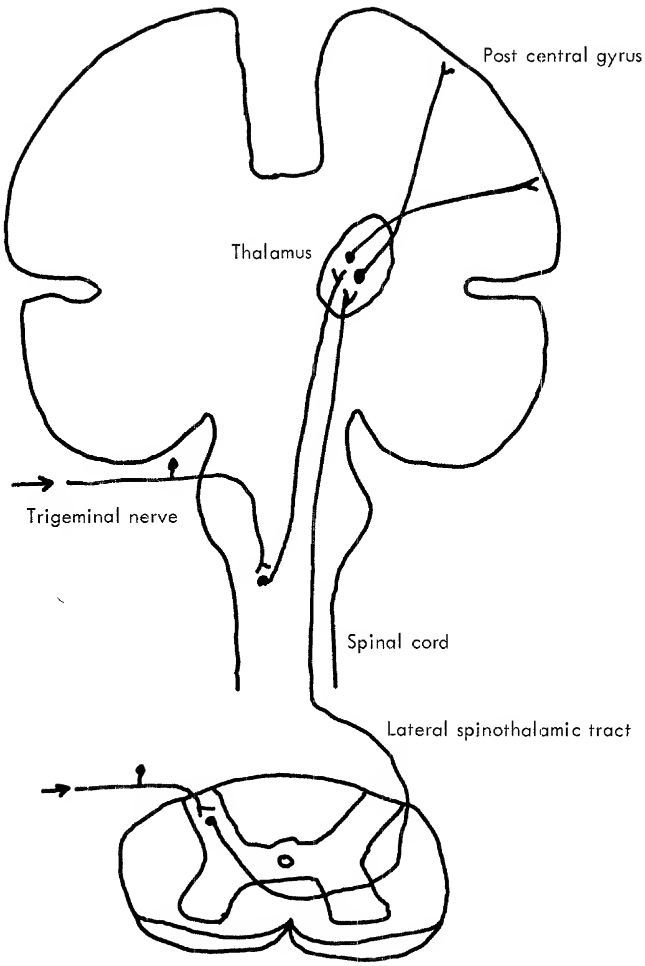


Fig. 12.2. Neural pathways for the pain senses.

The temperature sense is represented by ascending pathways of its own that follow the pain pathways quite closely in their course.

It is also important to realize that the skin is supplied by the nervous system in an orderly segmented fashion. Figure 12.3 shows *dermatomes*, or skin areas supplied by a certain posterior root of the spinal cord. Because the spinal cord is segmented in its internal neural structure, the area of the skin represented in the distribution of the spinal nerve is also segmented roughly in a cross-sectional manner from head to foot. Some complications are involved in the distribution of the innervations of the fore and hind limbs. This segmentation into dermatomes means that injury to

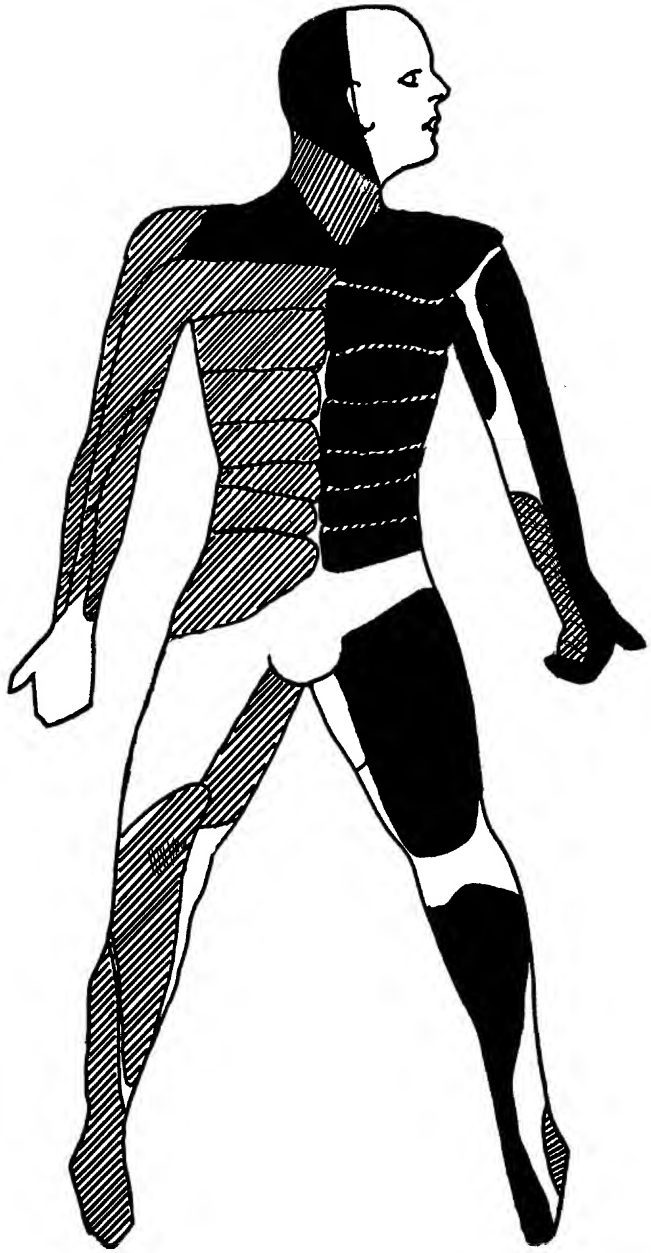


Fig. 12.3. The skin of the body, limbs, and head is divided into areas or segments (dermatomes) in terms of their nerve supply. Half the dermatomes are shown on the left and the other half on the right; the fact that the diagram is different on the two sides is meant to indicate that dermatomes overlap. (In a complete diagram, the areas would be lettered and numbered in terms of the particular nerves that supply them.)

given nerves results in sensory deficits in limited areas of skin tissue. Although there is some overlapping of nerve distribution, there are definite limits to each of the dermatonal areas.

The nature of threshold cutaneous sensitivity

One of the outstanding features of threshold sensitivity of the skin is its pointlike nature. This is true alike for touch, temperature, and pain. A slightly suprathreshold stimulus applied to the skin is not effective on all portions of the skin surface but only at certain points. At intermediate positions, no sensory result is obtained unless more energetic impingements are applied. As soon as contact is made more energetic, the pointlike nature of sensitivity is lost, and all portions of the skin, when contacted, result in sensation. The density of the distribution of "touch spots," "cold spots," "warm spots," and "pain spots" is not the same for all portions of the skin, nor are the different kinds of spots the same in concentration in any single region. This depends on at least two factors: variation in skin structure and variation in density of distribution of neural structures that give rise to the spots.

Although there seems at times to be some variation in the locale of these sensitive spots, their anatomical stability has been reported by various authorities. Dallenbach (1927) has relocated certain pressure and cold spots after an interval of more than a decade. The pointlike nature of threshold sensitivity of the skin was discovered independently by three men at about the same time: Blix in 1884 and Goldscheider and Donaldson in 1855 (see Goldscheider, 1911, 1917). The method of von Frey (1897)—the use of manually applied horsehairs—long ruled as the technique for investigating tactile sensitivity. In more recent years, several different investigators constructed electromechanical devices called *kinohapts* whereby tiny styli could be raised and lowered upon the skin with more or less uniform impact, and with precise timing. Bishop (1943) has used tiny electric sparks as cutaneous stimuli. This form of stimulation avoids the production of momentary distortions of skin tissue.

Another use of electrical stimulation is the application of brief shocks to a nerve trunk such as below the surface on the volar aspect of the arm. Here one can insert an electrode close alongside the nerve trunk and thereby be able to stimulate it. When one does this, he is not selecting out the fibers that carry impulses for a single cutaneous modality; instead the analysis is carried on by varying impingement intensity and rates of repeated stimulation. Thus this is not a mode of studying touch, thermal sensitivity, or pain solely or separately but a mode of making comparisons between them on the basis of simple impingement variables. Thus, if it is found that the experiences of touch are evoked with a weaker impingement than those of temperature, that is one important datum. If it is found that pain

experiences relate differently to repeated impingements, that, too, is important in building an understanding of the differences in the underlying mechanisms. For example, it was found that the first shocks of a certain intensity might not elicit a pain experience but, if the same value of shock were repeated at a given rate, a pain experience would emerge. At first it would be weak, but then it would build up as the shocks are repeated. This kind of result did not occur for repeated stimulation of the touch fibers. The analysis also disclosed that different qualities of touch are dependent on impingement level and rate of repetition.

Methods of dissociating the cutaneous experiences

Whereas cutaneous receptors have not been well identified, the separateness of the experiences and the pathways that subserve them have been demonstrated. In fact, there are six ways by which the dissociation is brought about.

1. Local anesthesia is accomplished in several ways. Sometimes it is done by nerve block. To understand this sort of dissociation, as accomplished by Heinbecker, Bishop, and O'Leary (1934), one must first be acquainted with their analysis of cutaneous modalities. They have disclosed, to their satisfaction, four forms of superficial cutaneous sensibility: touch, pricking touch, warmth, and cold. Pain is the experiential quality arising from suprathreshold stimulation of pathways of the pricking-touch modality. Perceptions of hot and burning arise from strong stimulation of warmth pathways. Deep cutaneous sensibility is made up of two modalities, pressure and pressure pain. Dissociation brought about by local anesthesia begins with effects upon the smallest nerve fibers and ends with the largest. The cutaneous sensibilities are obliterated in the following order: cold, warm, pain, and touch. Deep pain goes along with superficial pain, and deep pressure goes along with touch. Of course, upon the return of sensibility as the anesthetic wears off, the reverse order is shown.

2. The second form of dissociation involves complete loss of sensibility through injury or through asphyxiation (mechanical pressure block). In asphyxia, the first experience obliterated is light pressure, or touch. Thenceforth, the order is somewhat different from that obtained by the use of anesthesia by cocaine and procaine block.

3. Dissociation is produced also by removing thin slices of skin. This layer-by-layer technique provides for the disappearance of certain sensibilities before others, touch being the first to go.

4. Reliably different *chronaxies* for warmth, cold, touch, and pain have been obtained.

5. Spinal anesthesia produces some dissociation of the cutaneous senses. Likewise, nicking the spinal cord (that is, severing certain portions of it) may stop pain and spare touch.

6. Various pathological conditions result in dissociation, one of the outstanding of which is *syringomyelia,* a lesion that begins in the central gray matter of the spinal cord and moves toward the periphery. Pain is the first to disappear, while the other sensibilities are still intact. Warm and cold experiences go next, and finally the sense of touch. This is of course because various sensory tracts are separate and one is reached by the disease before the others.

COMPARISONS BETWEEN SKIN SENSATIONS AND HEARING

Békésy (1959) reported a series of ways in which the skin and the cochlea react to mechanical impingements. (The various means by which the comparisons were made are too extensive to be detailed here.) An experiment in hearing was first performed and then an analogous one was performed on the skin to see whether the results would be similar in pattern. The skin is a sensitive surface many times grosser than the basilar membrane of the cochlea, so in a way the comparisons consisted in performing experiments involving first a macroscopic body mechanism and then a microscopic body mechanism. Among the justifications for making the comparisons is the fact that in an evolutionary way the cochlea is a form of specialized skin.

Let us briefly examine one or two of the comparisons. The first pertains to the mechanical patterns that can be set up along the skin and the basilar membrane. If a vibrating stylus is placed on the skin, traveling waves are set up as shown in Fig. 12.4. These spread out in all directions, forming more-or-less concentric rings (Békésy, 1939a, 1940). They are only slightly damped and their wavelength decreases as vibration frequency is increased. Békésy reported that if the stylus is used on the arm at a rate of 50 cycles per second and with the proper amplitude, the waves may travel around the whole girth of the arm, but the experience of vibration is felt only under the tip of the stylus. Consequently, it is certain that although a large area is thrown into vibration, the sensory experience produced is limited to a very restricted spot.

Traveling waves are set up in the ear by acoustic stimuli. They spread from the stapes at the oval window and progress along the basilar membrane. They have a high speed near the point of origin and slow down in travel velocity as they go along. As was pointed out in Chapter Ten they peak at a maximum amplitude at some given distance along the membrane. The maximal amplitude varies in accord with the vibration frequency, being closer to the oval window the higher the frequency is.

What has been shown here is the resemblance between skin activity and basilar membrane activity. There is a difference in the two cases, however. On the skin, the maximal amplitude of the waves is at the point of

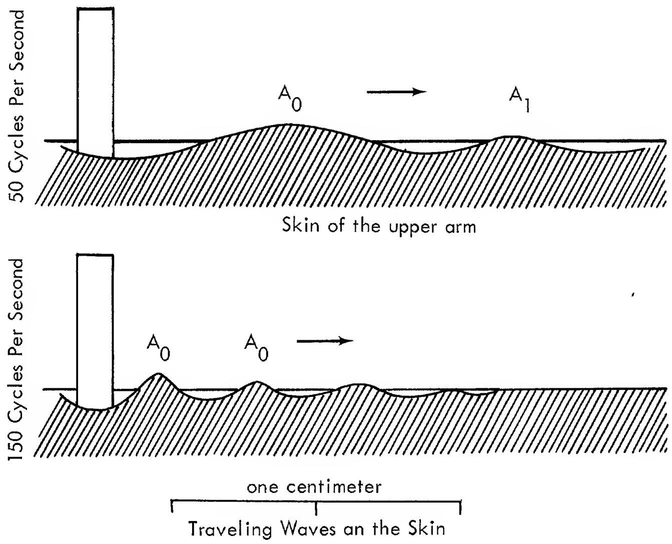


Fig. 12.4. Traveling waves in the skin set up by a contacting rod. The effect simulates the effect of an acoustic stimulus in activating the cochlea. (G. von Békésy. Similarities between hearing and skin sensations. *Psychol. Rev.*, 1959, 66, 1–22, Fig. 3.)

origin, whereas in the basilar membrane it varies in position with vibration frequency. Thus the basilar membrane and associated parts of the ear make mechanical positional analysis in accord with frequency.

Various parts of the skin vary in sensitiveness to pressure and vibration. Thus comparisons between the tactile and auditory mechanisms can be compared by using tactile areas of the skin of the two extreme sorts. It turns out that such comparisons manifest close similarities only when the most sensitive skin areas such as the fingertip are used (Békésy, 1955, 1958).

Under such conditions, comparisons between the *magnitude* of tactile sensation and auditory *loudness* turn out to be quite similar in principle. This is at its best when short clicks rather than sinusoidal vibrations are used. In addition to this, a delay in the emergence of maximal sensation is found in both cases. The maximum tactile sensation takes *time* to build up. Actually, more than a second must elapse before the skin vibration will be felt at its maximum, and about 0.2 second is required for loudness to reach maximum. If the vibration is terminated, a certain amount of time must elapse before the skin sensation vanishes completely, and a short lag occurs in the auditory experience.

The "size" of the sensation in the two cases shows some similarities. Skin sensations may change their size even when the vibrating surface area remains unchanged. In both touch and hearing, the experienced size

(volume, area) varies in accord with the frequency of the vibrating source. Apparent size declines as frequency rises.

Still other comparisons have been demonstrated, and it has been such comparisons involving both similarities and differences that have provided insights into the principles involved in sensory mechanisms that otherwise might not have been obtained.

TOUCH

Kinds of tactile experiences

The experience aroused by mechanical contact with the skin, usually called touch or pressure, is not always the same, and consequently a number of terms have arisen to label the variations. Among them, we have "contact," a lively and bright experience. "Deep pressure" is another, dull and heavy. Some pressure experiences are pointlike, some dense, some diffuse, and some even granular. One of the differentiating features that stands out is the degree of superficiality versus the degree of depth. Sometimes pressures emerge abruptly; others well up slowly. Apparently few kinds of cutaneous perception are simple in composition. Aside from mere touch and contact, there are special experiences we call *tickle, itch, vibration, creep,* and so on. Impingements that are displaced along skin surfaces give rise to the experience of tactual movement. Properly timed sequences of momentary stationary impingements also give rise to the experience of movement (or apparent movement).

For tactile experiences the most common stimulus is, of course, mechanical. Tiny masses (disks, styli, and the like) that are placed on the skin deform it to some extent or other. This deformation requires time. Gradients of skin deformation may be produced not only by applying the kind of impingement just mentioned but, for example, by immersing one's finger in a vessel of quicksilver (mercury). Everywhere but at the juncture of the air and mercury the pressure on the finger will be uniform. It is at the juncture that the greatest changes in pressure occur as the finger is moved. And it is there that the experience of contact will be felt.

What a tactual stimulus is

A most enlightening investigation on the fundamentals of the pressure or tactile sense was done by Nafe and Wagoner (1941). They constructed a precision instrument (Fig. 12.5) whereby pressures could be manipulated and minute differences in the amount of deformation of the skin measured. Their stimuli consisted in a series of disks of various areas and of different masses. Their instrumentation measured and recorded the rate at which these disks sank into the skin by force of weight or by instrumental determination. Their subjects were instructed to indicate, by pressing a key, when

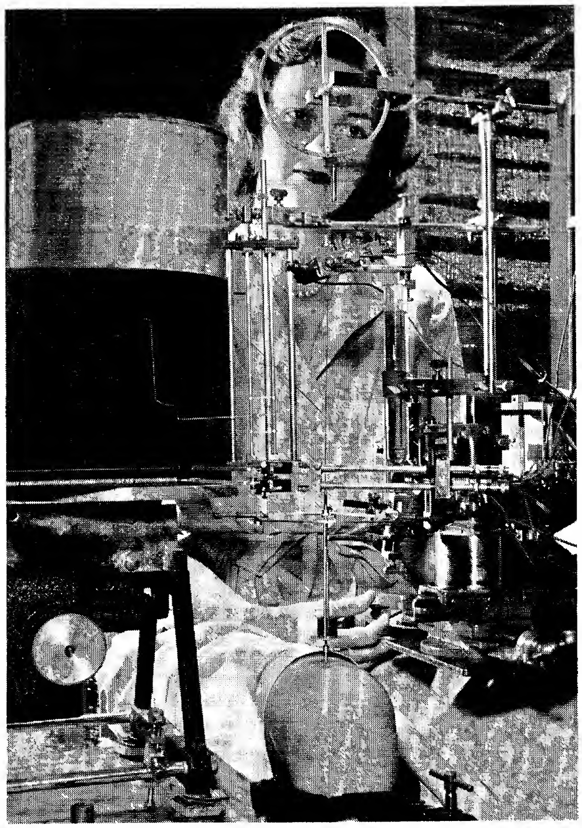


Fig. 12.5. Apparatus to study tactual response in relation to depression of the skin by styli of various areas. It provides not only for "free" depression of the skin but depression at a controlled rate. (Photograph by Paul Berg. *St. Louis Post-Dispatch*, Sunday Pictures.)

they felt the pressure of the disk and when they did not feel it. It was found that so long as the disk's "rate of fall" into (that is, depression of) the skin was above a certain value, the subject felt the disk's pressure. When this critical rate no longer was being maintained or exceeded, no experience of contact was produced.

The common-sense viewpoint makes stimulation the mere contact of the disk with the skin. Nafe and Wagoner had to substitute for this the idea that stimulation consists in deforming the skin. Without the deformation process no stimulation occurs. They found that not only was the process of deformation necessary, but the process had to occur at or above a critical rate to constitute stimulation.

It is customary to speak of *adaptation* as the cessation or reduction of activity of a sensory mechanism, while supposed stimulation is held uni-

form. The final failure of the disk to be felt has long been considered an example of tactual adaptation. Nafe and Wagoner had to attribute adaptation not to sense-organ failure while stimulation was held constant but rather to the termination of conditions that in themselves could be called stimulation. Hence, it could be said that what is ordinarily called tactile adaptation is not a sense-organ failure. One simply ceases to feel the disk when the process of stimulation ceases. On the other hand, if one must adhere to the older definition of adaptation—namely, that it is partial or total failure of the sense organ to be able to respond to stimulation—then our present tactile example is not one of adaptation at all. Nafe and Wagoner's concept of the stimulus, and why the disk finally ceases to be felt, avoids the curious paradox of talking about a stimulus that does not stimulate. For that reason, among others, it seems to be a very fortunate way of envisaging the situation. Nafe and Wagoner's interpretation also coincides with the general notion we have expressed in several earlier places —namely, that sense organs are made up of two sorts of tissue, neural and nonneural. Adhering to this concept, it would be said that the skin that surrounds the free nerve endings and other sensory endings is a part of the tactual sense organ. Tactile stimulation consists, then, in doing something to the nonneural part of the tactual sense organ. According to this, the skin does not become exhausted by "stimulation" (the presence of the disk). We simply do not keep the disk moving and thus are failing to continually deform the skin at a sufficient rate. This fails to produce some consequent effect that is the condition for setting up nerve impulses. When this is the case, we do not feel the disk.

Guilford and Lovewell (1936) made a study of the tactile spots on the skin based on the fact that, the more forcefully a stylus is applied to the skin, the more dense the distribution of the skin spots becomes. This relationship was implied in what was said earlier in this chapter.

Guilford and Lovewell's nine styli ranged from 0.01 gram to 1.60 grams. Each was applied to two hundred equally distributed locations on a one-square-centimeter area on the back of the hand (Fig. 12.6). As pressure was increased, a greater and greater percentage of all the spots responded. The sigmoid shape of the curve represented the relation between impingement intensity and density of spots. To some, this suggests that any unit area of the skin possesses some probability of responding to a given impingement of a given intensity.

Various calculations have been made concerning the minimal energy required for eliciting tactual experience. One author reported that 0.026 erg on the end of the thumb and 0.037 erg to 1.09 ergs on the tips of the fingers were threshold values. Comparing threshold tactual values with visual and auditory thresholds, it may be said that one hundred million to ten billion times as much energy is required by touch as by the other two senses.

Von Frey reasoned that if there are two separate senses, touch (or pres-

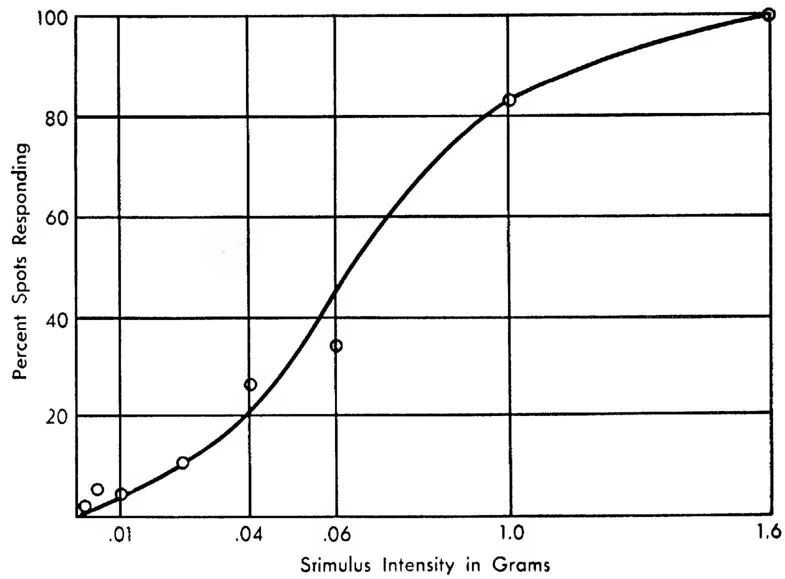


Fig. 12.6. Relation of pressure on skin to probability of response. (J. P. Guilford & E. M. Lovewell. Touch spots and the intensity of the stimulus. *J. gen. Psychol.*, 1936, **15**, 149–159, Fig. 1.)

sure) and pain, they ought to have separate thresholds. He believed that the threshold for the pressure experience should be lower than for pain. Accordingly, he carefully explored a restricted area of the skin on the subject's leg. In this area he found about fifteen points with a threshold of about 33 grams per square millimeter or less. He gradually raised the stimulus pressure and did not find any additional pressure spots. When a pressure of about 200 grams per square millimeter was reached, he began to elicit a pricking and painful experience. He also found that the distribution of the spots was different for the two experiences. From this he concluded that he had demonstrated the separateness of pressure and pain modalities. Table 2

Table 2. Cutaneous Thresholds

	PRESSURE (gm/mm^2)	PAIN (gm/mm^2)
Fingertip	3	300
Calf of leg	16	30
Forearm (back)	33	30
Forearm (front)	8	20

provides a few examples of thresholds for pressure and pain; it indicates that the relation between thresholds for the two experiences is not simple: In some, but not all, cases there is a wide distinction.

Tactual localization

Our interest does not lie solely in where on the skin tactual impingements can be felt but also in where impingements that are made are perceptually localized. Do subjects feel the contacts to be made where they are made? Renshaw and Wherry (1931), among others, have addressed themselves to this problem. They studied the ability of subjects to localize spots on the back of the nonpreferential hand and the flat surface of the volar forearm throughout a daily practice period ranging from 7 to 32 days, depending upon the subject. The subjects ranged from 8 to 65 years of age. Renshaw found rather large practice effects in both the young and old subjects. The children were not only more accurate than the adults but showed a more rapid reduction in magnitude of errors. During the first two days, the children localized the stimulus more accurately on the forearm than on the hand. The adults did just the opposite. Renshaw suggested that the poorer performance manifested by adults may be due to having handicapped the adults more than the children by the use of blindfolds in the experiment; the supposition was that the adults' behavior is more dominantly visually controlled than the children's. This idea was tested by using a procedure different from that in the first experiment. Four subjects were chosen: two adults 28 and 58 years of age and two boys 12 years of age. Two methods of reporting where the subjects had been contacted were used. One was the tactual-kinesthetic method of having the subjects quickly touch the spot felt to be the one. The other, visual method was simply to look at the skin surface upon which a grid had been marked and answer as to which square in the grid had been contacted. The adults did better by the visual method, and the children did better by the tactual-kinesthetic one. This was in the direction of a confirmation of Renshaw's idea that the dependence upon contact for tactual localization in children is substituted, as time goes on, by visual control of the performance. He suggests this substitution might occur near the age of puberty.

Renshaw, Wherry, and Newlin (1930) studied tactual localization in congenitally blind children and adults in comparison with sighted young and old. They found the following: Blind adults are superior to blind children in tactual localization. Blind adults are likewise more accurate than sighted adults. Sighted children are superior to sighted adults. Sighted children are superior to blind children. Initial performance is better on the forearm than on the hand for sighted children, but the opposite is true for all others. When the results of the blind are plotted age-wise, the results of the adults are a projection of those of the children.

The inferiority of the sighted adults with reference to sighted children is thought to be due to the shift in the adults to dependence upon distance receptors in localization—that is, to vision. Renshaw and Wherry (1931)

studied a group of subjects over an age range of 6 to 16 years to determine when ocular dominance in tactual localization sets in. They concluded that tactual-kinesthetic localization is superior to visual from the eighth to the twelfth year, at which point the difference vanishes. At puberty, there seems to be an increase in the accuracy for both methods. Between the thirteenth and fourteenth years, the visual method becomes superior and continues to become greater as age increases. The workers pointed out that when the children use the visual method (their poorer method) and the adults use the tactual-kinesthetic method (their poorer method), there is no true difference between their results. This would nullify the Rivers-MacDougall law that states that sensory discrimination is inversely proportional to age and degree of civilization of a population.

The findings of Renshaw and his colleagues bear on the findings of Bartley (1953, 1955) and his colleagues obtained on children compared to adults. In the study of whether children perceive block size in relation distance from the eye, it was found that children did the same at all distances and made smaller or fewer errors than adults. Putting all the information available together, it would seem to indicate that the children did not use visual imagery, at least to the same extent as the adults, and that visual imagery was responsible for the size-distance effect found in adults.

The tau effect

The tactile sense may be used to demonstrate one of the most fundamental principles in the process of stimulation, that both time and place are involved in defining or specifying stimulation. Tactual impingement reaches the skin not only at some *place* but at some *time*. It makes a difference, then, both in terms of time and place, what the end result will be.

Helson and King (1931) performed experiments on a phenomenon they called the *tau* effect because they did not want its name confused with those of other phenomena. The tau effect was demonstrated by contacting the skin in three places in temporal succession. (Fig. 12.7). Points A, B, and C were the three points of contact on the skin. The distance from A to B marked off space interval 1; the distance from B to C marked off space

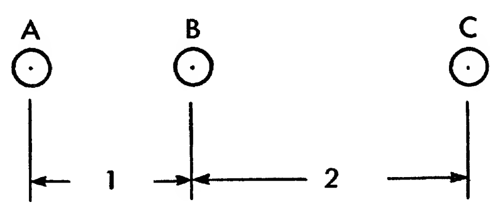


Fig. 12.7. The arrangement of spots contacted on the skin to produce the tau effect.

interval 2. The task of the subject, who was blindfolded, was to report which of the two intervals was the larger. Or, he could just as well have been asked whether space interval 2 was larger or smaller than interval 1.

The investigators used an instrument called a *kinohapt* (Fig. 12.8) to make contact with the skin at A, B, and C. There were of course several possibilities with regard both to spacing and timing. A and C could be equidistant from B lying between them, or A could be nearer to or farther away from B than C was. The same possibilities held true for the timing of

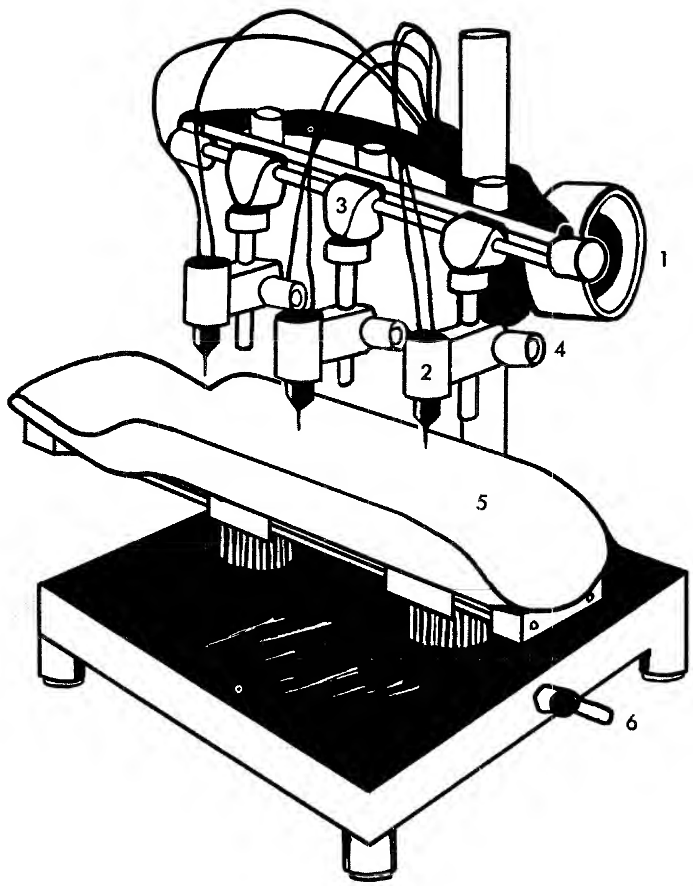


Fig. 12.8. A Bartley kinohapt, an electro-mechanical device for contacting the skin with tiny styli with precise pressures and time relations. Item 1 is the knob for adjusting the whole carriage vertically; 2 is one of the solenoids activating a stylus; 3 is a solenoid carriage adjustable horizontally; 4 is a knob adjusting a single solenoid vertically; 5 is the arm rest, adjustable in all directions; 6 is the armrest lock.

the contacts. A, B, and C could be presented with an equal interval between A–B and B–C. Or the first time interval could be longer or shorter than the second. Furthermore, the timing and spacing would be related to each other in various ways.

Let us assume that space intervals 1 and 2 are equal and time interval 1 is longer than interval 2. The subject is likely to report that space interval 1 is the longer. This effect can still be maintained when space interval 2 is made longer than 1. The procedure is to determine how much longer than time interval 2 time interval 1 must be to have the space intervals appear equal. As the time intervals are made unequal, the space intervals must also be made unequal in the opposite direction.

We can now turn to some of the findings of Helson and King, summarized in Table 3, in which the first column shows time interval 1 divided

Table 3. Time and Space Intervals

t_1/t_2 (msec.)	RATIO	s_2/s_1 (mm)	RATIO
500/200	2.5	50/30	1.67
500/250	2.0	45/30	1.50
500/300	1.67	40/30	1.33
500/350	1.43	35/30	1.20
500/400	1.25	30/30	1.00

by time interval 2. In the third column, space interval 2 is divided by space interval 1. The ratios of columns 1 and 3 are given in the second and fourth columns. The ratios are the ones found necessary by Helson and King to make space intervals 1 and 2 appear equal. For time intervals of 500 and 200 milliseconds, the space intervals were 30 and 50 millimeters, respectively. That is, while the time intervals were to each other as 2.5 to 1, the space intervals were not quite the actual reciprocal, but rather 1 to 1.67. To make the two spaces appear equal required time compensation and in milliseconds it was greater than would be expected in simple reciprocity.

According to the common outlook, the tau effect is a *time-space illusion*. But it is to be recognized that the results were perfectly according to law and depended upon the operation of time and space factors in neural activity.

To see how certain variations of the procedure work, we turn again to Helson and King. Instead of contacts A, B, and C lying in a straight line, they were now the corners of an equilateral triangle. With this new and very different arrangement, the manipulation of timing as the contact sequence was followed through changed the apparent shape of the triangle to non-equilateral. Also, the investigators contacted the two points instead of three in the order A, B, A. When the timing was different in going from A to B from going from B back to A, it did not seem as though A was being contacted upon return. By this result it was shown that a given point on the

skin does not possess, in itself, some unique property whereby it is localized. The point lies in a cutaneous field, controlled by both spatial and temporal factors. Helson and King's investigation was a demonstration of the fallacy of Lotze's theory of *local signs*, in which it is asserted that every point on the skin possesses its own unique and sufficient characteristics for being localized when stimulated.

We must remember that space and time are operants of two sorts for us. On the one hand, they are concepts applicable to operations performed or processes observed. In introducing the tau effect, we said that stimulation involves places on the skin and places in the nervous system at which processes occur. We said that the processes that occurred, occurred in time and that the relative timing of several neural processes controlled the perceptual end result.

Space and time are also to be looked upon as something *perceived*. There are spatial and temporal features of perception. Helson and King's study involved space and time in both ways. Once we see how space and time are involved in neural processes, it is not so surprising to see them involved in perceptual response (experience).

WARMTH AND COLDNESS

Stimulus conditions

In principle, the stimulus conditions for the experiences of warmth and coldness arise out of the fact that the human as a warm-blooded organism maintains a fairly constant internal body temperature but his skin temperature is quite different. Skin temperature is not nearly so constant and its mean level is lower; it depends partly on the level of outside temperature and partly on the moment-to-moment nature of the blood supply to the skin. Generally there is a temperature gradient downward from internal body temperature to skin surface temperature. The temperature of whatever contacts the skin may differ from the skin-surface temperature up or down and thus may add or subtract heat from the skin. Various factors converge toward producing what has long been called a *physiological zero*. If the temperature of the impingement, whatever it may be, is higher than physiological zero at the time, a feeling of warmth is generally produced; if lower, the feeling of cold ensues. This is not always the case, however, for there is such a result as a *paradoxical cold* and also, according to some investigators, a *paradoxical warmth*.

Paradoxical results

When impingements with a temperature higher than physiological zero produce the feeling of cold, the result is called paradoxical cold. When impingements below physiological zero produce the feeling of warmth, the

result is paradoxical warmth. However, the paradoxes exist only so long as one has no understanding of how they are produced.

Paradoxical coldness is produced not by activating "warm spots" by "warm stimuli" but by activating "cold spots" by "warm stimuli," and for this it was found that a stylus temperature of 45° C (113° F) or a little higher is required. A stylus at 33° C (91° F) is usually high enough to elicit warmth. To obtain paradoxical coldness, the stylus usually must not contact much skin surface; with extensive contact, "warm spots" are also activated, giving the experience of warmth. If, however, the skin is first well-heated up, say to 45° C, and then a stylus at 48° C is applied, coldness will be the first experience elicited, with warmth following a little later.

Paradoxical warmth is less commonly elicitable. One experimenter believed that slight warmth could be elicited by a stylus at about 0.1 to 1.5° C below physiological zero. Another put the range for paradoxical warmth at 6° to 10° C below physiological zero. The conditions for producing this form of warmth have not been well established.

Alrutz (1900) scaled the experiences produced by contact styli above physiological zero, as follows:

At the first thermal threshold	Experience of slightest warmth
Above this threshold	Marked warmth
At paradoxical cold threshold	A kind of warmth called heat
Above this threshold	Heat resembling cold
At next higher (pain) threshold	Burning heat
Above this	Pain itself

Lowenstein and Dallenbach (1930) studied these thresholds on one hundred subjects at a room temperature of 20° to 25° C (68° to 77° F). The experience of heat was produced by styli at 40° to 46° C (104° to 114.8° F). The average was close to 43° C (about 109° F).

In recording from peripheral nerves in the tongue, Hensel and Zotterman (1951) found a group of mechanoreceptive fibers also activated by cooling. Their response to cooling differed from that of true cold-mediating fibers, however. The mechanoreceptive fibers could be activated only by extremes in cooling and terminated their discharge when thermal conditions were made stable. In the radial nerve, Hensel and Boman (1960) found fibers that responded to mechanical stimulation and manifested a steady discharge when the temperature of the skin was in the indifferent range even when no mechanical impingement was involved. Cooling increased the discharge slightly. Witt and Hensel (1959) found the same phenomenon in the cat. These results might explain the so-called Weber illusion of pressure, produced by cooling. Lippold, Nicholls, and Redfearn (1960) found that some of the muscle spindles they studied in the cat responded to thermal ("cold") stimuli quite like specific "cold" fibers while maintaining a normal response to stretch.

This overlapping or cross-modality response probably accounts for a number of the everyday sensory effects such as people feeling cold when they have extensive aches in their muscles. In some cases, there is a nebulous kind of discomfort interpreted as feeling cold, but the feeling may not mean that the person is cold in the usual sense of the word. Kenshalo, Nafe, and Brooks (1961) found that at somewhat extreme temperatures sudden thermal charges produce two readily distinguishable sensations, the occurrence of each depending upon the size of the change.

The heat grill

A unique way of producing the experience of heat is a *synthetic method* involving the use of a "heat grill," which consists of a set of small copper tubes in which alternate parallel tubes carry water at different temperatures. One set of tubes used alone would elicit the experience of warmth; the other would elicit coldness. This arrangement tends to produce first an experience of coldness, then of hotness, and then a possible return to coldness. Heat is produced by this method without the use of high-temperature stimuli.

Woodworth and Schlosberg (1954) pointed out that paradoxical cold and synthetic heat are by no means the most frequent results elicited when making thermal explorations of the skin. Only two out of Jenkins' (1938) four subjects reported paradoxical effects at all and then only 27 times in 9000 observations. Geldard (1953), on the other hand, stated that paradoxical perceptions of cold are produced commonly enough in mapping warm spots.

The explanation for divergence in effects when several observers place their wrists upon a metal grid in which alternate rods are of different temperatures of suitable values, has to do with the observer's set and with his quickness of responses. There are those who retract their hand quickly as though burned. Others are slower. The time required for the experience to emerge is shorter for cold than for warmth, and warmth emerges before pain. For observers who draw their hand away quickly, all that should be experienced is coldness and warmth, but they report hotness. For those who keep their wrists on the grid a little longer, the distinctions between cold and warm are more likely to be experienced for what they are.

Contact and radiant stimulation

So far we have been reporting results from thermal stimulation through contact. Thermal effects can also be transmitted to the skin by radiation. The two methods lead to different results. It seems that warmth cannot be experienced at all when restricted areas of radiant impingement are used. When skin areas of less than 700 square millimeters are radiated,

pain is experienced when radiation is strong enough to elicit any experience. When contact styli are used, areas as small as a single square millimeter or even less may be effective in eliciting warmth. Whether this distinction has some meaning in the economy of the organism is not known.

In line with what was just said about large areas being required for the effectiveness of thermal radiators, it can be said that spatial summation is characteristic for this form of stimulation. The energy needed per unit of skin area to produce threshold results is much less for two regions than for one alone. Summation is marked enough to show up when the two areas are represented by the backs of the two hands. It is not equivalent for all portions of the skin, as is shown by the fact that two regions, one the hand and the other the forehead, will not summate to the same extent as if the two test regions are on the two hands.

Until recently it was thought that the receptive area on the skin for a single nerve fiber conducting thermal information was a small spot less than one millimeter in diameter. Kenshalo, Decker, and Hamilton (1967) found that the discharge in a fiber is augmented when any of eight different spots are cooled. In other fibers tested, numbers varying from two to six spots were involved. The activity in the fibers increased in a summative fashion as additional spots were added to the first one cooled. Since psychophysical experiments had shown that areal summation occurs in the production of the experience of cooling, the present experiment would seem to demonstrate one neural factor that works in that direction.

Thermal adaptation

The skin adapts to thermal conditions. That is to say, thermal conditions felt as warm or cold cease gradually to feel either way with an elapse of time during which the impingement condition exists. The course of this thermal adaptation is a negatively accelerated curve (Hahn, 1930).

At temperatures close to the usual skin temperatures, adaptation is short. Hensel (1950) reported that at temperatures outside the range of 20° to 40° C sensation does not disappear. When single small spots are tested, adaptation is rapid even at temperature extremes.

To adapt to a thermal level is not only to become sensationless for that level but to shift in the experience produced by thermal levels just above and below. Those above feel warm; those below feel cold.

It is known that fibers sensative to thermal conditions do not increase uniformly as temperature changes but instead show one or more peaks of sensitivity. That is, they are activated maximally at certain levels throughout a range. The explanation of this fact is quite different from explaining activities of fibers as monotonic functions (that is, increasing or decreasing regularly as temperature changes). Certain central inhibitory functions are suggested for this: reciprocal inhibition would provide for adaptation (Deutsch and Deutsch, 1966).

Kenshalo and Scott (1966) undertook new measurements of temperature adaptation because the literature reported various results, of, for example, changes in sensation with concomitant thermal changes in the skin, and because at the terminal stages of adaptation sensation waxes and wanes, making judgments of the end-point of adaptation quite difficult. The older methods of ascertaining temperature adaptation involved exposing the skin to an extreme temperature for a period such as that provided by cold water and then ascertaining the temperature of a bath at which a warm sensation was induced. In another method the course of temperature adaptation was ascertained, including the determination of its limits, by exposing the skin to specific temperatures and asking the subject to report when he no longer felt warmth or coldness. Kenshalo and Scott felt that these methods were undesirable because (1) it is difficult for a subject to attend to a sensation even for a single minute, let alone for 40 minutes, and (2) the second method fails to produce a clear-cut end-point because the determination of the instant of no sensation is extremely difficult, if not entirely impossible.

Hence, Kenshalo and Scott undertook a different method—namely, a variation of the method of average error. In this, the subject controls the temperature of the stimulator to maintain a given level of sensation. The device they used was able to control the temperature within $\pm 0.01°$ C. At the end of a 20-minute foreperiod, the dorsal surface of the forearm of the subject was measured by a thermocouple. The stimulator was adjusted by the subject so that a just-detectable experience of warm or cold was maintained throughout a period of 40 minutes. At 5-minute intervals, the experimenter changed the temperature toward neutral and instructed the subject to adjust it till a just-noticeable sensation was produced. This technique produced a range of complete adaptation much smaller than ranges reported by previous investigators. Complete adaptation was 8.2° C in one subject and 4.5° C in another, whereas values of 23° C, 27° C, 21° C, and even 40° C were obtained by four other investigators, respectively. Adaptation was completed in from 10 to 20 minutes in Kenshalo and Scott's study.

Theories of temperature sensitivity

Since we are not as much concerned with bodily mechanisms as physiological psychology textbooks are, or textbooks solely on the senses, we shall not spend much effort on theories of temperature sensitivity. We are more concerned with the personal behavior that stems from stimulation of sense organs.

The classical theory of temperature sensitivity rests mainly on the supposed correspondence between distribution of sensitivity and distribution of certain end organs. Attempts to correlate structure and function have not been very rewarding. At present, we cannot say for sure which

form of specialized ending subserves the function of the temperature experiences.

A much more recent theory of thermal sensitivity is Nafe's (1938). It can be called a neurovascular theory. He believes that the smooth-muscle walls of the blood vessels of the skin—arterioles, for example—are responsible for thermal experience. In the walls are free nerve endings, button-formed endings, and terminal loops. It is supposed that contraction and relaxation of the vessel walls activate these endings in appropriate ways. The resulting neural activity is utilized by the central nervous system to provide the ultimate experiences of warmth and cold. This amounts to saying, then, that temperature perceptions are a form of kinesthetic or muscle-induced experience. Nafe rests his case upon the reports of various investigators to the effect that smooth muscle is thermally sensitive, relaxing in certain upper-temperature ranges and contracting in ranges below them. Much of what is proposed in Nafe's neurovascular theory is quite convincing; nevertheless, his theory does not at once tell us why the two kinds of temperature spots are distributed differently. The best we can say is that at present the understanding of the mechanisms responsible for temperature sensitivity leaves much to be desired. Geldard (1953) suggested that nerve tissue is directly sensitive to thermal conditions and thus no specialized nerve endings would be needed for mediating temperature experiences. The generality seems too broad, however.

Kenshalo and Nafe (1963) made simultaneous measurements of changes in the threshold for "cool" impingements and of cutaneous vasodilation as a function of the temperature to which the skin was adapted. The changes in the two measures occurred in close correspondence, suggesting to these investigators that the cutaneous vascular system may be valuable as a temperature detector model and thus may contribute to a theory of temperature sensitivity.

Detection of thermal conditions in the surrounds

One function of the temperature sense is to "inform" the organism of the thermal nature of its surrounds, which are made up of three kinds of thermal condition. One is the set of conditions that involve *radiation*, either to or from the organism. Sources of radiant energy such as fires, lamps, stoves, and the sun radiate to the body. Other situations involve radiation from the body when its temperature is lower than the surrounds. The second thermal impingement, to which the organism is obviously sensitive, is the process of *convection*, as for example in air currents. The third process is *conduction*, the transfer of heat by contact.

All three conditions are encountered by the organism in its moment-to-moment activities, and when near-equilibrium thermal conditions exist there is no conscious realization of temperature on the part of the organism.

It is generally only as these optimal or equilibrium conditions are departed from that awareness of warmth or coldness arises.

Whereas pointlike radiation to the skin is ineffective in producing perception of warmth, large skin areas are extremely sensitive to radiation. Certain investigators have reported that only a trivial radiation playing onto the forehead produces the experience of warmth. An increase in radiation intensity of only 0.0014 calorie per square centimeter per second, inducing a rise in skin temperature of only 0.003° C, was felt as warmth.

Solids with which the body comes in contact vary widely in their property of conducting heat. We experience the difference in the way common solids feel to the touch. A stone bench is colder in winter and hotter in summer than a wooden bench because of a difference in thermal conductivity. Metals are among the coldest and hottest of objects. The conductivity of silver is about 18,000 times as great as the air. Cotton is about seven times as conductive and glass is about 44 times as conductive as air. Hence, the way these substances feel could be expected to be quite different in various circumstances.

Regulation of body temperature

The organism employs temperature sense modalities in the maintenance of body temperature. This activity is, in general, spoken of as homeostatic and reflexive.

It is easy for us to think of temperature regulation of the body as being solely a vegetative (or vital) process carried on by reflex mechanisms and thus very different from perception. It may be recalled, however, that in an earlier chapter (page 9) reflexes were classed as perceptual responses if and when they involved the cerebral cortex and were immediate discriminatory responses to environmental conditions. Temperature regulation is an instant-to-instant response to environmental conditions and, at least at times, involves the cerebral cortex and is discriminatory. At such times, it is a form of perceptual response.

The regulation of body temperature is better understood when it is thought of as a system of exchanges of heat back and forth between the body and its surrounds. There are four factors in this system: metabolism that produces heat, evaporation that always transfers heat from the body, convection that either takes heat away from or gives heat to the body, and radiation that also may cause the body to lose or gain heat.

The human environment is divided functionally into three different temperature ranges (Fig. 12.9). The upper is called the *range of vasomotor and evaporative regulation* and runs down to about 86° F. Below this, for a distance of about 4° F, there is a *neutral* or *transitional zone*. Below the transitional zone, the range is spoken of as the *cold range* or the *zone of body cooling*, beginning at about 82° F. These values pertain to unclothed

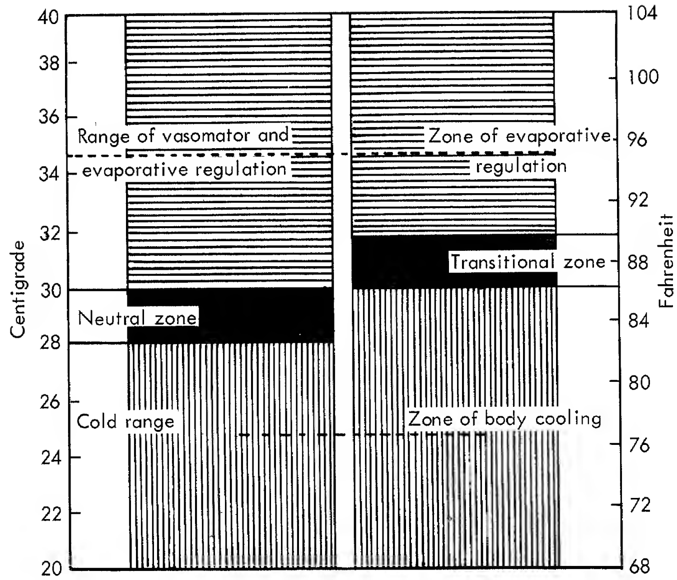


Fig. 12.9. The functional zones of environmental temperature as specificed by Hardy and Soderstrom (on the left) and by Gagge, Herrington, and Winslow (on the right).

resting subjects, and, of course, do not represent environmental temperatures that apply when clothes are worn and active body movement occurs.

In the range of vasomotor and evaporative regulation, the blood sent to the skin and superficial tissues increases with environmental temperature. Evaporation from the body also rises, but not in any simple or uniform fashion, with temperature. Skin temperature rises only a little. Body heat loss slowly increases. It turns out that, even though a working equilibrium of body temperature is maintained under such environmental conditions, personal comfort diminishes.

In the neutral or transitional zone, heat loss is well adjusted for by shifts of blood to or from peripheral tissues by vasoconstriction and vasodilation. Personal comfort is at its maximum. Perhaps it is some feature of the rate of heat loss that is effective in giving the maximum body comfort. This sort of perception would in a large part be mediated by the temperature sense organs.

Some authorities say that in the cold range no regulation of heat loss occurs. The body loses heat just as does any inanimate mass of substance. If one is cold under such circumstances, he must seek a new environment, put on more clothes, become more active physically, or do something that directly changes metabolic rate. Individuals vary greatly in their degree of discomfort under given low-temperature conditions.

Since humidity conditions of the atmosphere alter the rate of evaporation from the human body, humidity also figures in human comfort and in the efficiency with which body temperature regulation is carried on.

One of the most recent investigations that seems to bear on the role that the temperature sense mechanism plays in body-heat regulation is that of Benjamin, Wagner, Ihrig, and Zeit (1956), who cooled a group of canine subjects from 100° F to 80° F in 20 minutes by leading the animals' blood from the carotid artery to an outside cooling system and back again. That is, the animals were made to circulate their own blood through an outside cooling system while they were in a room of normal temperature. This manner of cooling was accomplished without the usual unfavorable symptoms of cardiac fibrillation, shivering, and other shock manifestations. In some cases, the temperature was reduced to the point of complete stoppage of the heart. The animals were rewarmed by using the outside system to rewarm their blood. When return from the low temperatures reached a certain point, heart activity returned. When the animals were warmed up to 90° F, they were able to go on from there—that is, they reached their original temperatures without further artificial warming. The point we wish to make is that, under ordinary cooling conditions, cooling is accomplished by putting the animal's body in a cool environment. That is, the body is made to cool from the surface inward. In the technique just described, the cooling was accomplished through the blood stream and thus uniformly produced temperature reduction.

It would seem that the second way of cooling in effect by-passed the temperature sense mechanism—that is, cooling was accomplished without activating this mechanism. If so, then the avoidance or omission of shivering and other systemic manifestations could be attributed to this avoidance. The facts suggest, then, that the temperature sense plays the initiating role in activating certain compensatory reactions to cooling. If cooling goes on in spite of the initial compensatory reactions, still more drastic reactions set in. If cooling by-passes the reaction-initiating system (the temperature sense), it can be accomplished without much, if any, harm to the organism. Obviously, nature unaided could not work this way. If they are to survive, animals must "kick up a fuss" about being subjected to untoward situations. If, on the other hand, the same agency that subjects the organism to the otherwise unfavorable condition avoids activating the alarm mechanism and also takes care that the animal is restored to normal, then the whole procedure goes along reasonably well and in a manner very different from what we should expect from our common-sense background.

Physical conditions and comfort

Winslow, Herrington, and Gagge (1937) studied relations between physiological conditions (such as sweating), physical conditions (tempera-

ture and humidity), and the feeling of body comfort (or better still, personal comfort).

The investigators used a five-point scale, varying from very unpleasant to very pleasant, for the subjects to indicate their feelings. It was found that as relative humidity increases, the environmental temperature at which distinct pleasantness is lost drops (Fig. 12.10). The zone of perceptual

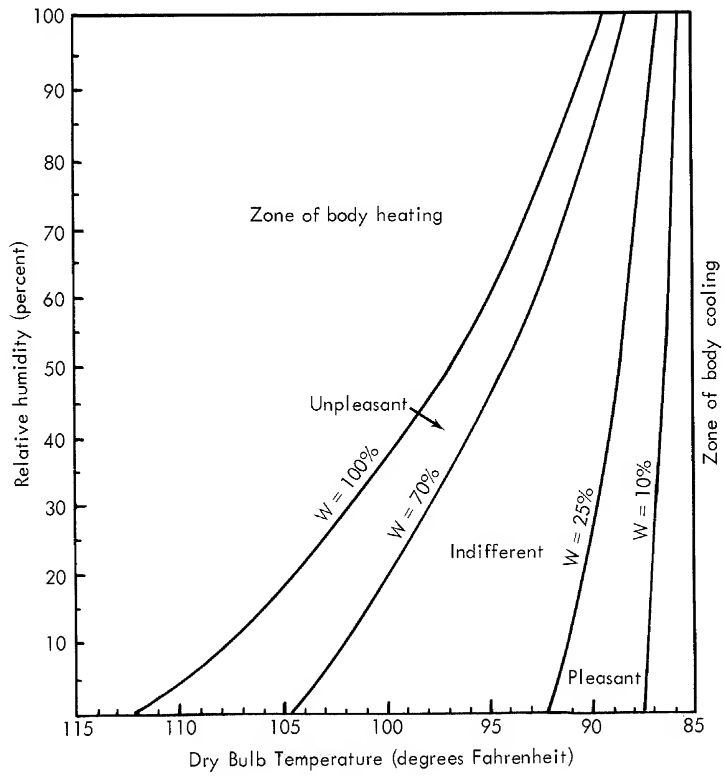


Fig. 12.10. Relation between sweating, environmental temperature, relative humidity, and the feelings of comfort and discomfort in the semireclining, unclothed subject. W is "wetted area," a measure of sweating used in this kind of investigation. As relative humidity rises, the ranges of indifference and pleasantness contract. (C. A. E. Winslow, L. P. Herrington, & A. P. Gagge. Relations between atmospheric conditions, physiological reactions, and sensations of pleasantness. *Amer. J. Hygiene,* 1937, **26,** 103–115.)

indifference narrows as relative humidity becomes greater. For example, whereas with dry air the subjects exhibited a temperature range of indifference between 104.5° and 92° F, when relative humidity rose to 50 percent the indifferent range contracted to between 95° and 89.5° F.

PAIN

Painful experiences can be elicited by doing something to the skin. The usual stimulus for touch is mechanical. The stimulus for warm and cold is thermal. The stimulus for pain may be thermal, mechanical, chemical, or electrical.

Laboratory experimentation on pain has employed several distinct kinds of stimuli, among which have been: (1) mechanical impingements, to discover thresholds and distinguish between points on the skin mediating pain and touch; (2) thermal radiation, as applied for example to the forehead; and (3) electrical shocks applied by electrodes inserted under the skin alongside a nerve trunk.

Among the questions that have arisen is how specific a form of impingement must be to evoke pain. That is, might not a variety of forms of impingement, if intense, evoke pain? One thing that can be said in this connection is that certain questions regarding the close connection between tactile and painful sensations do arise in using certain stimuli.

Electrical stimulation

We shall begin by reporting on certain findings brought out by Bishop (1943, 1944, 1946, 1949) and his colleagues (Heinbecker and Bishop, 1934; Heinbecker, Bishop, and O'Leary, 1934) using electrical stimulation in studying the relations between cutaneous sensations.

One of Bishop's investigations (1944) disclosed what he called a "peripheral unit for pain," conceived of as the tiny skin area served mainly by a certain branching nerve fiber. Anywhere within this skin area a weak stimulation will elicit a kind of sensation, depending upon actual intensity. The threshold will be lower in the center of the area than at the periphery. The skin area does not correspond, however, to any well-defined describable anatomical nerve-ending distribution to which a specific pain experience can be assigned. Peripheral units overlap each other, and it takes careful exploration to detect any behavior that would lead to the concept of the peripheral unit for pain.

The sensory experiences arising from the activation of a peripheral unit for pain vary in keeping with the nature of the stimulation applied. Bishop's stimulation consisted in trains of tiny electric shocks that he could vary in intensity and in rate of delivery to the skin. These factors determined various rates and durations of afferent neural discharge to the central nervous system. The perceptual experiences that resulted differed, accordingly, in both qualitative and quantitative properties.

At the lowest threshold, an "inconsequential" touch experience is elicited; at a little higher threshold, a pricking experience is elicited; with

certain specifications of stimulation, itch or pain ensues. If two skin units are stimulated concurrently or by alternate bursts of electric shocks, a two-point discrimination between them is possible. That is, the two separate loci, each being stimulated, do not summate into pain. Some adjacent points, when stimulated, result in a modified effect. That is, they neither summate nor are recognized as two separate spots.

The electrical threshold for the prick endings is lower than for touch endings, and this precludes complicating the experiment by stimulation of the true tactile sense, at least at threshold. However, shocks strong enough to induce pain may elicit nonpainful touch. Touch is more sharply localized than pain is. Even so, one might ask whether pain and touch are not unavoidably confusable. Bishop (1943, 1944, 1946) pointed out that the two are distinguishable by differences in their temporal characteristics. Touch is "deadbeat"—that is, a separate brief experience occurs to each shock. Prick and pain, in contrast, are persistent and rise gradually rather than abruptly to maximum. A ten-per-second rate of administration of shocks to a touch spot will not summate or induce a fused sensory end result. On the other hand, pain from such stimuli will rise to its maximum only after five or six shocks have been delivered. Pain also persists for almost a second following the cessation of stimulation. Thus shocks at a ten-per-second rate are, in a way, a single continuous stimulus rather than many separate ones. The maximally sensitive skin areas for pain and touch are generally not identical in location. If a maximally sensitive spot for pain is stimulated, touch will generally not be aroused by the range of stimulus intensities used.

It can be seen, then, that pain spots are identifiable and the results of stimulating them are distinguishable from the results of using similar stimuli upon nearby skin areas identified as touch or temperature spots.

Experimential end results elicited by activation of the mechanisms giving pain are, at their lowest thresholds, not painful but have a pricking quality by no means describable as pain. Pain is elicited only by more intense or longer trains of stimuli.

The analysis of pain mechanisms, pain qualities, and pain thresholds by this electrical method gives somewhat different impressions to the experimenter from those he receives from mechanical or other methods. In all cases, however, the investigator ends up with the conclusion that he is dealing with a different mechanism from that involved in producing tactile and thermal experiences.

Central pathways for pain

The impulses set up in fibers for this modality travel toward the brain in both myelinated and nonmyelinated fibers, at rates ranging from 30 meters per second to less than a meter per second. This produces two distinct arrival times for reaching the central nervous system. (The sensory

consequences of this will be dealt with in the next section.) The fibers branch profusely after entering the spinal cord. Many of the branches establish reflex connections, some of which we shall mention later. Figure 12.2 shows the pathway.

Are there two pains?

It has been concluded that the fibers carrying information from pain-producing impingements, are of two sorts: A fibers that conduct impulses at high velocity and C fibers that conduct impulses much more slowly. We know that there are two main qualitative sorts of pain, the prick pain (a bright relatively short pain) and dull pain (longer lasting and more diffuse). Some have argued that the bright pain is mediated by A fibers, dull pain by C fibers. One sort of evidence for fiber mediation comes from the results of differential fiber blocking produced by cocaine. This affects C fibers first and A fibers last. When only A fibers are conducting, pain is of the brief, pricking sort. By another form of differential block—pressure that halts circulation—A fibers are blocked first and C fibers last. When only C fibers are conducting, the pain is dull.

As early as 1892, Gad and Goldschneider, and then Thunberg in 1902, reported that there are two pains rather than the expected single pain to certain stimuli. These were identified by the time interval separating their onset. Though this double effect is not too hard to demonstrate, Jones (1956) claims that it need not be interpreted as an essential duality but as only due to certain kinds of impingements reaching different fibers at different times by differential penetration of different depths in the skin. He demonstrated that some kinds of stimuli do not produce two pains.

Zotterman (1933) showed that when A fiber conduction is blocked the pain that predominates is the second pain.

Special forms of pain

The usual textbook presentation of pain ends with a good description of what has been found by topical explorations of the skin. We shall not stop there, however, for we have something to say about pain in tissues other than the skin and about pain in the economy of the human individual.

Much of the pain the average individual suffers is localized *within* the body. This noncutaneous pain possesses the greatest significance in the life and economy of the individual. Looked at from one standpoint, the study of pain is just a consideration of one of the several forms of body sensitivity that have been investigated in the laboratories of sensory physiology and psychology. Not too much is yet known about it except the kind of facts mentioned in the previous sections. Looked at in another way, pain is one

of the most important subjects in all psychology, for it is through pain that most bodily derangements are expressed. It is in the form of pain that such troubles are made known to the individual himself. It is through the nature and location of pains that much of medical diagnosis is made possible. Moreover, pain is a kind of personality expression. Some individuals experience pain for which medical men can find no bodily correlate. It behooves psychologists to give serious attention to pain.

Although the word *pain* is widely used, it does not have as precise a meaning as could be desired. Accordingly, very subtle problems arise in its use in both scientific and professional circles. Up to this point, we have dealt with pain as simply one of the several sense modalities we possess. But it is used with several other connotations as well. There are times when what seems to be rather moderate tissue involvement results in a very distressing personal state. What is felt is all out of proportion to what might be expected. It has been difficult to account for this under the old concepts of how the organism functions. But when we realize that in all cases the sensory experience is an expression of the way the central nervous system utilizes peripheral input, we begin to make sense of the results. A quotation from Bishop (1946) is relevant:

> Pain is unique in the degree to which its arousal overflows into affective or emotional protest, although other senses also share this capacity, which may be accentuated or depressed in abnormal mental conditions. Below a certain intensity, whose level varies both with mental and emotional states and under anesthetics and analgesics, pain may be perceived without significant affective reaction. Below the intensity of stimulation required for pain, activation of pain endings induces sensations qualitatively different from pain, as prick, itch, etc., depending on the pattern of stimulation. These non-painful "pains" fused with touch and temperature may contribute to the complex sensations of casual experience not recognized as partaking of the character of pain.

The forms of pain we are now dealing with carry the implication that they may involve a considerable affective component.

The four kinds of pain that constitute the topics for this section are *headache, spontaneous pain, referred pain,* and pain spoken of as due to *neuritis* (in which is included neuralgia, although at times it seems to be partially a form of central pain).

All that is to be said about headache is based on its distinction as intracranial pain. Nevertheless, the origins of headaches are so complex and so poorly understood that it is possible they possess something in common with other forms of pain that we shall distinguish.

Spontaneous pain, sometimes called *central pain,* is to be distinguished from other forms by the fact that its origin does not seem to be in the stimulation of sense organs. In fact, it is attributed to lesions in the central nervous system itself.

Referred pain is still another kind of phenomenon inasmuch as its origins generally lie in the activation of peripheral tissue though the localization of the experience is at some site removed from the point of stimulation.

Neuritis involves a form of pain presumably originating from an abnormal condition of the nerve sheath.

HEADACHE. One of the commonest and most distressing forms of pain is headache. As a form of human experience, it should be considered by psychologists. Headaches can be dealt with from the standpoint of what apparently causes them. They arise not only from malfunctioning body mechanisms but also from nondisease origins such as personal conflict. This is tacitly recognized in the everyday use of the word "headache" as a symbol for nuisance and other forms of personal trouble. Our first task is to discover the body mechanisms that most immediately underlie headache. This is somewhat easier than determining the many conditions that set into motion chains of events leading to this form of pain. One of the most direct attacks of the problem consists in determining what intracranial structures give rise to pain.

Penfield (1935) has found that the dural sinuses [7] are particularly sensitive to pressure, traction, heat, and electrical stimulation. Disturbance of the middle meningeal artery and its dural branches likewise gives rise to pain. Cerebral vessels in general are insensitive except for an occasional vein near a dural sinus or low in a brain fissure. The skull and the brain are themselves insensitive to cutting and to electrical stimulation.

Regardless of the types of stimulation used, the only forms of experience that can be elicited from within the cranial cavity are pain or pressure. The individual usually calls his experience headache, pressing ("splitting") pain, or sharp pain. Pain elicited from adequate disturbance of the meningeal arteries is usually sharp and fairly restricted in locality. Pain elicited by action on the dural sinuses is generally referred to another part of the head.

Clark, Hough, and Wolff (1936) produced headaches by administering histamine and measured both the cerebrospinal fluid pressure and the blood pressure within the cranium. They concluded that the headache following the giving of histamine is produced by the difference in the behavior of the blood vessels inside the cranium and elsewhere in the body.

[7] The brain is covered by two connective tissue sheaths, one of which is the *dura mater*, generally called dura. Sinuses are pockets or cavities in the organism and dural sinuses are formed at the junctures between the medial and transverse partitions in the dura mater. These dural sinuses are part of the venous circulation system and are thus filled with blood that ultimately empties into the internal jugular vein. The sinuses thus drain the blood from the brain. They represent portions of the dura that would mechanically be most likely to be subject to stress owing to variations in blood pressure and to the fact that they lack the solid masses of brain tissue on both sides as exists elsewhere along the dural partitions.

Systemic blood pressure is raised, but the cerebral blood vessels dilate and consequently are less able to absorb pressure changes of the arterial pulse. These mechanical changes are thus left to affect more intensely the sense organs in the vessel walls. The authors suggest that the same mechanism operates when various vasodilators—such as amyl nitrite, carbon monoxide, and foreign proteins—are taken into the body. Clark, Hough, and Wolff found that raising the arterial pressure or lowering the cerebrospinal pressure during headache intensified the pain. Likewise, raising the cerebrospinal pressure or lowering the arterial pressure decreased the pain. From this, it would seem that the adjustments that returned the relationships between the pressures on the two sides of the arterial walls toward the normal balance reduced pain. This seems to be true regardless of whether the vessel walls dilated.

CENTRAL OR SPONTANEOUS PAIN. In most cases, spontaneous pain has been attributed to lesions in the thalamus. Early in the century, Head and Holmes, two outstanding men in brain pathology, believed that the thalamus was responsible for the feeling tone that accompanies visceral and somatic sensation. This doctrine has since become quite widespread. More recently, however, other evidence has indicated that lesions in the spinal cord, cerebrum, medulla, or even in peripheral regions, as well as those in the thalamus, can cause spontaneous pain.

It has been reported that cranial nerve lesions produced "burning sensations" localized along the distributions of the nerve. Certain spinal-cord lesions were accompanied not only by central pain but also by vibratory sensations and distorted thermal sensations (cold being called hot). In two cases, for example, in which no thalamic lesions were found but in which there were lesions in the parietal cortex, central pain existed. This was associated with the impairment of deep pressure and tactile sensations. In most of the cases reported, spontaneous pain was associated with lesions involving incomplete destruction of the spinothalamic tract.

It would seem, then, that lesions in a variety of locations might be expected to result in central pain. Further study may tend to show, however, that although central pain and distortions in sensation may result, lesions in the thalamus result in effects somewhat different from lesions elsewhere.

REFERRED PAIN. We have already seen that in the conditions producing headache the principle of *reference* (discrepancy between locus of stimulation and locus of sensation) is at work. When the dural sinuses are mechanically disturbed, the pain is felt not in the sinuses but elsewhere. Part of this apparent reference could possibly be brought about by mechanical effects transmitted to tissue distant from the point of application. This is not the general interpretation in these cases, however.

Referred pain as it is commonly spoken of has to do with pains felt in the body wall when the disturbance lies in the visceral organs. One of the most marked origins of this form of pain is the heart, as in the production of *angina pectoris*. In this affliction, pains are not localized in the heart but include intermittent pains ranging from dull oppressive sensations to severe intolerable pain about the sternum, often radiating to arms, throat, and face. Many "heart pains," however, have no relation to the heart or its blood supply but are common phenomena in high-strung, overworked individuals and may be related to the vague state called "nervous hyperirritability."

The neural pathways for referred pain have not as yet been delineated with satisfactory certainty. Among the routes suggested are:

1. Visceral and somatic impulses may lead into a common neuron in the spinal cord. The combined innervation would tend to make many subthreshold excitations from the body rise above threshold. When this occurs, the location the pain is referred to is the skin and skeletal muscles, for example, rather than the viscera.
2. Visceral afferent impulses may set up "reflex" actions on blood vessels of muscles, skin, meninges, and so on, by causing release of chemical substances or indirectly through vasomotor changes. The ultimate result would then be activity in somatic fibers leading to the cord and sensations of disturbance in the skin or muscles.
3. Visceral afferent impulses may conduct in the reverse direction (antidromically) along certain branches of their axons, either before or after they have entered the spinal cord. The antidromic impulses act on blood vessels, and affects such as suggested in paragraph 2 take place. The pain that results is, of course, referred to skin, skeletal muscles, and so on instead of to visceral structures.

Whatever the exact mode of transmission of effects, referred pains are an indubitable phenomenon and must be taken into account in interpreting painful sensations.

NEURITIS. Neuritis in peripheral nerve trunks is of two sorts: inflammatory and degenerative. Whatever the disturbances are, nerve tissue is stimulated and the result is pain in the somatic members involved, particularly when there is muscle movement. Some physiologists suggest that, since mechanical and vascular influences are involved in the former, and chemical and toxic in the latter, a closer study of disturbances of pain, tactile, and temperature modalities might help distinguish the type of neuritis existing in any case. The services of psychology might be of help in diagnosing such diseases. Physiologists point out, however, that most of the pains usually attributed to neuritis do not arise from changes in nerves but rather as referred pain from joints. Thus, they may be arthritic rather than neuritic.

SUMMARY

This chapter on the senses of the skin has included the sense modalities of touch-pressure, pain, and warm and cold. The latter has come to be regarded, in many quarters, as two senses (warm and cold) instead of simply a single temperature sense. This is based not only on experiential distinctions but upon pathways involved.

In the introductory section, the structure of the skin, including the specialized end-organs, was described. This was followed by a delineation of neural pathways for the skin senses. Next, the nature of threshold cutaneous sensitivity was described; this, of course, constituted the description of its point-like nature. Methods of dissociating the sense mechanisms from each other were given. This section described Békésy's comparisons between skin sensations and hearing.

The second section of the chapter dealt with touch. An important feature of this section was a discussion of what constitutes a tactual stimulus; it has turned out to be quite different from what was ordinarily supposed. Certain experiments on tactual localization were included, and Helson and King's *tau* effect was described as an example of sensory relativity.

The section on warmth and coldness discussed the paradoxical effects sometimes produced and their relation to the particular types of end-organ involved. Theories of temperature sensitivity were included, as was the role of the temperature modality (or modalities) in temperature regulation. Following this, a discussion of the physical conditions, physiological conditions, and the feeling of comfort was given.

The final section, on pain, included not only attention to the analytical investigation of pain experience as made in laboratories but also the clinical experience called pain. Here it was pointed out that these two experiences might well be two different things with a common label. The laboratory experiences could be given the name of pain and the clinical could be called anguish, the two being forms of distress.

The several kinds of pain, headache, spontaneous pain, referred pain, and neuralgia, were differentiated.

THIRTEEN

Modalities for Bodily Movement, Posture, and Manipulation

⚘ We address ourselves in this chapter to the problem of mechanical orientation to the earth, or ground, and the gravitational system, which involves movement and maintenance of posture. Various tissues are involved, including skin, connective tissue beneath the skin, periosteum, bone, sheaths of tendons and muscle fascia, and capsules of joints as well as muscle. It also includes the nonauditory labyrinth (the vestibular mechanism). Each is involved in ways a little different, and the various tissues do not all contain the same sorts of simple and specialized receptors. The tissue organization not only accomplishes movement and regulation of posture but also provides several sorts of experience. We are interested here in position, posture, and movement but also in the experiences evoked. Much of this activity has long been included under kinesthesis and vestibular activity (the sensory feedback from motor tissues and the input from the nonauditory part of the ear).

KINESTHETIC ACTIVITY

Classification of muscle, tendon, and joint mechanisms

Charles Bell was in 1826 one of the first, if not the first, to describe the sixth sense, the *muscle sense.* He described the pathways to and from the muscles to the brain. Much later, Sherrington coined the term *proprioception;* Bastian used the term *kinesthesia;* Head used *position sense* and *appreciation of passive movement.* Added to this is the term *somathesis* to cover not only the muscle and joint sense but other bodily senses as well.

In dealing with what we shall call kinesthesis, several classes of con-

sideration are relevant: (1) the types of energy effective either in eliciting and guiding movement or in eliciting sensation; (2) the specialized end organs in muscles, tendons, joints, and other deep tissue; (3) fiber sizes (diameters) leading from specialized sensitive structures to the central nervous system; (4) relation of end organ activity to sensation and to motor activity. In considering further classifications, one should be careful not to inadvertently intermingle them and thus become confused.

KINESTHETIC SENSE RECEPTORS. Several sets of sense receptors belong in the kinesthetic category. Two are in muscle tissue, one is in tendons, one is in the fascia of muscles, and still others are in and around joints. Within recent years they have been given the simple designations A_1, A_2, B, and C endings, respectively.

The A_1 ending is called the *flower-spray ending* and is activated by passive stretch of the muscle—that is elongating tensions not originated by the attempt of muscle itself to shorten (or contract). It appears that active muscular contractions terminate the impulses originating the A_1 endings. About one-half of all of the fibers in muscle are associated with A_1 activity. Another nerve ending, the A_2 ending, is named more or less in accord with its appearance: the *annulospiral ending*. It also is sensitive to passive muscle stretch. Thus, both the A_1 and A_2 endings are called *stretch afferents*.

Type B endings are very specialized structures and are said to be activated either by an increase or a decrease in tension at the junctures between muscles and tendons. It is probable that no distinction between muscle contraction and passive muscle stretch is possible in this case. The B endings have higher thresholds than the A endings, but the impulse frequently set up in them manifests a lawful quantitative relation to tension. It is roughly proportional to the logarithm of the tension.

The C endings are probably the *Pacinian corpuscles* that are found in the fascia (the sheaths) of the muscles and tendons. Golgi tendon organs are of course found in tendons. Small Pacinian corpuscles occur at joints but the more common structures are the Ruffini endings. In general, it is thought that Pacinian corpuscles are organs of deep pressure wherever they are found, for they are found not only in muscles and tendons but also in subcutaneous tissue. The Pacinian corpuscle adapts fairly quickly to the initial activating agent and thus differs from other proprioceptor organs. The fact that they adapt quickly and are activated by pressure is reminiscent of more superficial tactile (or pressure) perception. Nafe and Wagoner (1941) attributed adaptation not to sense-organ failure but to termination of conditions that could be called stimulation.

Finally, a possible form of neural endings that may have something to do with signaling the state of muscle are the ubiquitous *free nerve endings*. Many of these may have something to do with pain and with temperature in association with blood vessels. There is a plentiful supply of small endings distributed in muscle, ligament, tendon, fascia, and joint.

The nerve-muscle complex (the working unit) called a *neuromuscular spindle* consists in one or more muscle fibers, each innervated by small motor nerve fibers (*gamma afferents*) and by one or more large sensory nerve fibers. These form either the annulospiral ending already mentioned or a flower-spray ending. The nerve and muscle fibers are covered by a connective tissue capsule that is surrounded by fluid. As was stated earlier, the neuromuscular spindles are sensitive to variations in tension occasioned by increase in muscle fiber length. In addition, impulses from the gamma afferents cause the spindle fibers to contract, activating the sensory endings in the spindle complex.

There are also encapulated endings in tendons called *neurotendinous spindles*. These are the Golgi tendon organs and are activated by tension in tendons occasioned by either contraction or stretch of the associated muscle.

Connective tissue beneath the skin, periosteum, bones, sheaths of tendons or muscle fascia, and capsules of joints may also be involved in eliciting sensations. Collectively, the experiences are sometimes deep sensibility. Traditionally, kinesthesis was thought of as a muscle sense, but now there is considerable evidence (Rose and Mountcastle, 1959) that the stretch receptors of muscle do not play the role of informing the organism of joint position. Most of this evidence comes from neurophysiological experiments. Whatever the role of receptors in muscles, it is not primarily to inform regarding joint position nor, therefore, posture and movement.

Receptors in the joints seem to be the agents for informing of position and movement. The spray-type endings in the capsules of the joints are now imputed to signal steady position of the joints and the direction, rate, and extent of joint movement. In a given joint, for example, different groups of the total receptor population are activated, (each for their own angle of limb flexion and joint movement). That is, some receptors are excited for one angle of flexion, others for still other angles. Some are at one end of the range and some are at the other, so as to be excited at full flexion and full extension, respectively. This has been most extensively studied in the knee joint of the cat. Another slowly adapting receptor much like the Golgi tendon organ has been found in the joint ligaments. That the kinesthetic sense is not to be thought of as a muscle sense but rather as a joint sense is demonstrated by the fact that appreciation of limb positions and movement may be destroyed but leave muscles unaffected. The very opposite situation has been known to occur when the muscles and skin have been anesthetized. This has been accomplished with the sparing of the joints and the retention of appreciation of limb position.

CENTRAL PATHWAYS. The sensory pathways from muscle, joint, and tendon tissues play two roles: elicitation of reflex activity and the information that results in appreciation of movement, position, and so forth. The fibers from the latter enter the cord and ascend in the posterior funiculi to the

nucleus gracilis or nucleus cuneatus (Fig. 13.1). The corresponding sensory paths from the head and face are separate and unique. All kinesthetic paths end in the post central gyri of the opposite parietal lobes.

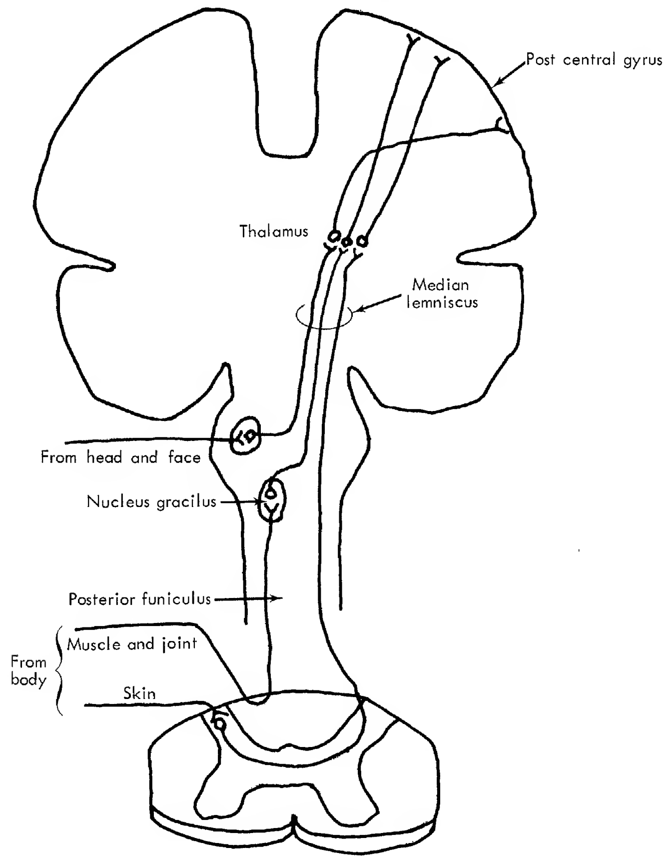


Fig. 13.1. Central pathways for muscle, joint, and tendon sensations.

VARIATIONS IN JOINT SENSITIVITY. Not all joints are equally sensitive to movement. Goldscheider's study (1898)—in which he attempted to measure minimum angular limb displacement (velocity constant) and at other times the minimal velocity discernible—indicated that the ankle is least sensitive and the shoulder most sensitive. The results of a more recent study by Laidlaw and Hamilton (1937) were in rough correspondence to Goldscheider's. They found the hip more sensitive than the shoulder and the main joint of the large toe (not measured by Goldscheider) the most sensitive of all. In general, articulations at the major points seem to be more sensitive than the finger and toe joints.

The Weber fraction

Some of the earliest of all psychophysical experimentation was done in kinesthesis. It was in kinesthesis (specifically, in weight lifting) that Weber's work (1846) led to *Weber's law.* Weber pointed out that a smaller difference between two weights can be detected if they are lifted than when they are simply placed on the skin; in other words, kinesthesis is more sensitive than touch in differentiating weights. Weber also concluded that the difference in two weights had to be at least 0.025 (1/40) of the value of the standard weight in order to be detected; this fraction is called the *Weber fraction.* The principle applies to discrimination in the other sensory modalities, although the size of the fraction varies from modality to modality. Some who followed Weber did not find the fraction to hold true throughout the whole range of values they tested. Some investigators found that the fraction decreases as the total weight of the standard is increased. This principle seems to apply to other features of kinesthesis, such as the force of movement.

Ladd and Woodworth (1911) reported a study of Biedermann and Lowit in which the fractions for lifted weights varied from 1/21 for weights of 250 grams, 1/114 for 2500 grams, and 1/99 for 2750 grams.

Kinesthesis and positioning movements

Psychologists today are studying the ability of people to make certain kinds of movements. A main feature of these movements is their accuracy. Whereas such studies may be thought of as solely studies of motor performance and not of sensory performance, we see them in a different light. The very basis for being able to make movements according to some predetermined pattern is the feedback provided by the kinesthetic sense. A description of the upper limits of performance is, in a way, a description of the characteristics of the kinesthetic control of movement. Among the kinds of movement studied are blind-positioning, visual-positioning, continuous adjustive, and repetitive.

Blind-positioning movements are often divided into restricted-positioning movements and free-positioning movements. With the former, it has been found that people overestimate short distances between one and 4 inches and underestimate movements between 4 and 15 inches. Positioning movements are more accurate away from the body than toward it. The smallest relative error and variability occur for distances within the range of 4 and 15 inches. In general, the accuracy of free-positioning movements is somewhat better below the subject's shoulder than at the shoulder level or above it. Upper portions of the target are undershot, while those at the lower portions are overshot. This estimation of positions as too high is not consistent, however.

To move between two predetermined end positions takes about as long for a distance of 5 inches as for one of 15 inches. Rather than attaining speed in a constant time after starting, the subject simply moves faster for a longer distance. If the distance is short, the hand accelerates more slowly than if the distance is longer. Thus, very little time is saved by shortening the movement distance. Apparently, the greater the distance is, the faster the arm moves. Thus the movement is adjusted pretty well for the distance, all distances within certain limits requiring about the same time.

Two kinds of repetitive movements have been studied: tapping and cranking movements. Preferred tapping rates, or the comfortable rates for continued tapping, vary between 1.5 and 5 per second. It is not a very stable rate and can be changed by any one of a number of conditions. The rate over a range of from 1 to about 40 millimeters is not altered much by the amplitude. The highest tapping rate is achieved when most of the arm is employed—that is, wrist motions alone will not yield a rate as great as the whole arm. The poorest tapping rate is achieved with fingers alone.

In cranking movements, the rate drops as radius is increased. When radius is increased from 2.4 to 24 centimeters, the rate is reduced to half. Thus, in cranking the movement rate tends to compensate for distance. Factors that tend to reduce motor coordination or make the task more difficult tend to shift the best performance to greater radii.

It is possible that some day such findings regarding movements will be of service in better understanding the mechanism of stimulation of the kinesthetic receptors and the institution of the experience of movement.

Kinesthesis and orientation

Reid (1954) reported a so-called illusion of movement complementary to the well-known visual horizontal-vertical illusion. Blindfolded subjects moved a stylus in a required direction and then attempted to simulate this movement but in a direction at right angles to the first one. He found that the movement to right or left is "underestimated." Movements toward and outward from the body in the median plane are "overestimated." It is reported that the same overestimation and underestimation occur with reference to speed of movement. Reid concluded that movement up and down (that is, in a vertical plane) is equivalent to movement away from the body in a horizontal direction.

It was found that there was a significant positive correlation between judges' ratings on the wrestling ability of subjects and their "acuity of kinesthesis." Subjects were asked to maintain a uniform pressure against a moving object in a "dynamic situation." The more uniform the pressure was, the more keen the so-called kinesthetic acuity was. The results might be interpreted as suggesting an intimate interrelation between muscular skill and kinesthesis. In situations in which extensive muscle groups would be required to perform up to some measurable criterion, such as uniformity

of position or pressure, kinesthesis would certainly be dominantly involved. The ability to use both muscle and kinesthetic information to the best advantage would be expected. Unused muscle groups would not perform as smoothly, nor would the kinesthetic feedback from them be so helpful in performing to a criterion as would trained muscle groups.

Edgington (1953) studied the kinesthesis of motor performance. In one experiment he studied the influence of certain factors upon the ability of a subject to look where he is pointing and to point where he is looking. In both cases, the pointing arm was shielded from view. He found the variability of localizing was greater when the subject looked where he pointed than when he pointed where he was looking. In turning their heads to look where they were pointing, the subjects did not turn far enough.

Tactual-kinesthetic perceptions of straightness

Hunter (1954) examined twenty blind and twenty sighted subjects. He had them explore target edges tactually. Both groups perceived as straight an edge that curved away from the subject. But the edge perceived as just barely curved was metrically more nearly straight for the blind than for the sighted. That is, for the blind the perceptually straight corresponded more closely to the geometrically straight than it did for the sighted. The blind, both as an overall group and individually, behaved more consistently than did the sighted. Hunter attributes this to a "more highly developed organization of the blinds' tactual-kinesthetic perception."

In line with what we have already said about visual imagery operating in conjunction with the other sense modalities when they are activated, we would suggest that the higher variability of the sighted might well be due to the inconsistent use of visual imagery.

Touch and kinesthesis in size perception

Bartley (1953) tested the hypothesis that visual imagery plays a role in the perception of size when the tactual and kinesthetic modalities are activated, as, for example, in the grasping of a target that is not seen. It is well-known that it is very common for an individual to try to visualize the contacted target in order to perceive best what it is or what size and shape it is. The person is eager to know what it looks like.

Bartley used a number of different tests, including one in which his subjects ran their index fingers around the edge of the vertical face of a block. A standard, placed at a fixed distance from the blindfolded subject, was compared in this way with metrically equal, smaller, and larger blocks, at the same distance from the eye, and at positions nearer to and farther from the eye.

It was Bartley's supposition that if visual imagery played a predominant

role, the distance from the eye at which the contact was made would affect perceived size. Perceived size should diminish with distance. This was thought to be in accord with the idea that the block would be visualized as smaller the farther away it was. Bartley, in this and in several other tests, received evidence in favor of the expectation. It is in line with this that we stated in the preceding section that we supposed the blind were more consistent and nearer to metric straightness than the sighted because of the latter's use of visual imagery and possibly in an inconsistent way from trial to trial.

It is to be kept in mind here that kinesthetic feedback occurs in reaching to contact the block. It is likely that a kinesthetic factor as well as a tactual one is involved in the operation of perceiving size, under the experimental conditions used. If so, it would oppose the visual-imagery factor. This is the hypothesis stated by Bartley, Clifford, and Calvin (1955) in a further study of the performance just discussed.

Tension

Much of the usual reference to kinesthesis is rather indirect. One of the more familiar forms of reference pertains to muscular tension. What is called tension has several aspects. Sometimes it is called personal tension or nervous tension. It is, on the one hand, a kind of experience that has to do with one's own state and relation to his surrounds, particularly with the task demands that he recognizes are being put upon him, and, on the other hand, it is a stated or implied muscular or neural condition. The nature of the components and their interrelation have never been precisely described. To say the least, the kinesthetic mechanism is involved in some way, so that part of what can be called tension is evidenced in a sensory way.

In the limbs and in some other members, skeletal muscles are arranged in pairs and may act against each other or in reciprocity. In movement, muscle pairs act in some degree of reciprocity. When one member of the pair contracts, the other relaxes and elongates. This opposition may be in the form of easy-going reciprocity or a tug of war. Reciprocity may occur in many temporal patterns to produce the many forms of skeletal movement we know the human subject to be capable of. Tension in muscle is not only more or less phasic (producing motion) but is also residual. Motor responses do not occur and complete themselves but last on as residual tensions.

The state of tension in various muscle groups may vary from a minimum during sleep to a maximum under high excitement when awake. Part of this may be spoken of as tonus necessary for the maintenance of posture and other action against gravity, and part of it may be excessive.

The neck muscles are said to be crucial indicators of the general level

of the individual's muscle tonus. The head is a fairly heavy structure, significantly involved in the balance of the body. The eyes, as distance or space receptors, and the vestibules, the organs of equilibrium, are located in the head. The muscles of the neck are governed in some respects by certain patterned innervations called neck reflexes, which have to do with head positions with reference to gravity and the body. (Reflex activity is discussed at the end of the chapter, page 377.)

CENTRAL EFFECTS OF MUSCULAR TENSION. We have already spoken of the connection of muscular tension with experiential states, but nothing was said regarding cause and effect.

There are two general ways in which tension is alleged to be involved. The one is the case in which the central nervous system is the origin, as when an individual is involved in meeting a task demand. In doing something to meet the demand, effectiveness greatly varies. Often, a part of the ongoing activity is expressed not in regulated and coordinated movement or in effective thought, but in the mere building up of static tension in skeletal muscle. *Irradiation* is one expression of this, the progressive involvement of more and more musculature during the performance of a prolonged task. This may happen, for example, in writing a long letter. The writer starts out by using only the restricted musculature that is needed to move a pen, but he ends up by using arm, neck, back, and so on.

On the other hand, muscle tonus and tension are involved in helping sustain the excitation level of the cortex. Freeman (1948), who has given a great deal of attention to muscle tension and motor activity, calls the peripheral input from the muscle a backlash and credits it with the task of maintaining alertness. Kinesthesis, then, can be seen to play a role in personal alertness.

Not only does muscular activity, including muscular tension, send a sustaining innervation into the central nervous system by way of kinesthetic channels but it also produces the feeling of effort. When a task is difficult, there is likely to be a greater fraction of the total activity spent in excess tension than when the task is easy. When there is little diversion into this ineffective sidetrack called tension, the task *feels* easy; when tension is at its height, the task *feels* difficult.

RELAXATION. The question of the relation of muscle state to alertness, sleeplessness, and other special conditions of the individual is not clearly understood. The physician and scientist Edmund Jacobson (1957), who has concerned himself the most with this, has taught people to relax their muscles and has found that the relaxed muscular state is conducive to personal tranquility and the alleviation of anxiety. Jacobson has obtained concrete evidences for both the relaxed and the tense muscular states by recording muscle action potentials. From his work, it is evident that a

material degree of effective muscle tension exists even when the individual is unaware of it.

An essential feature of Jacobson's teaching of progressive relaxation is to get the trainees to become aware of tensions in particular muscle groups of the body one at a time. This is not as easy as might be supposed. For example, if one bends his hand backward he does so of course by contracting muscles lying in the back of the forearm. One would expect the tension in this muscle group to be felt, but this is not immediately so. What is felt is tension at the wrist, which Jacobson terms strain. But until the person becomes aware of the tension in the muscles just indicated, he cannot learn to relax them. Training to become aware of tension in specific muscles is carried out from group to group throughout the body, and once awareness of tension has been achieved relaxation can be produced by "letting the tension go," lessening tension till it can no longer be felt. This skill is improved by awareness of less and less amounts of existing tension. It is assumed that guidance of muscle behavior depends on being aware of certain sensations. Relaxation is the release or "letting go" and is associated with the disappearance of the feeling. The most expert are those who can detect the least tension when it exists.

Organic kinesthesis

Kinesthesis pertains to smooth muscle as well as skeletal. That is, there is neural feedback of some sort that may or may not have sensory consequences. We do know that there is sensation in some cases, such as stomach cramps. The exact relation, if any, between gastric muscle activity and sensorily based hunger is not well known even though it has received study; it is one of the many areas in sense perception still in need of exploration. It is logical, however, to suspect a connection and so to mention it here. If various patterns and degrees of tension in the muscles of the stomach walls have associated with them some kind of sensation, we can speak of this as organic kinesthesis. But even if this awareness is lacking or minimal, the muscles in the stomach must have a sensory feedback system, which would still be called organic kinesthesis, as in contrast to skeletal kinesthesis.

Kinesthesis and the feeling of well-being

It can be assuredly stated that a great deal of one's feeling of vigor, well-being, fitness, and so forth, as well as their opposites, is expressed in muscular terms. Kinesthesis properly covers all forms of sensory feedback from muscles, tendons, and joints that would convey such states. So, it is appropriate to think of kinesthesis as the medium for expressing moment-to-moment general fitness and comfort and their opposites. As a figure of speech, it may be said that "we live largely in our muscles."

THE VESTIBULAR SENSE

The vestibular sense is a mechanism whereby the organism relates itself to the gravitational field. In most cases, it is assisted in this by one or more other sense modalities, namely, kinesthesis, vision, the tactile sense, and even audition. The sense organs for the vestibular mechanism are in the nonauditory part of the inner ear.

There are two major aspects of the organ's relation to gravity. One is change in the rate of motion, called acceleration. The other is static posture, in which relations to gravity are just as inescapable as they are in changes in rate of motion. The *semicircular canals* function so as to detect acceleration and the *otolith organ* detects head posture. These two kinds of information are relayed to the appropriate parts of the central nervous system, where necessary movements of muscles are brought about to maintain the needed static body posture or to carry out motor performances without coming into conflict with gravitational demands.

Acceleration is of three general kinds. The first is *linear,* in which motion in a straight line is speeded up or slowed down. Slowing is called either deceleration or negative acceleration. The second kind of acceleration is change in direction of motion and is called *radial* acceleration. This is the constant change in direction of motion as one is rotated about a point. We are all familiar with examples of its action (centrifugal force), such as mud flying off a revolving wheel. *Angular* acceleration is the change in rate of a revolving object. Thus one undergoes angular acceleration as a merry-go-round slows down or speeds up.

Is there a vestibular sense?

Few items of information regarding the activity of the vestibular mechanism have come from sensations. There never has been agreement as to whether there are unique sensory qualities coming directly from vestibular activity. Wendt (1951) listed several reasons for this: (1) It is not certain that there is a cortical projection area for the vestibule. (2) It is very difficult to distinguish possible vestibular from kinesthetic sensations. (3) There is no vocabulary to distinguish experienced motion from physical motion. And, (4) added to this there is sheer intellectual difficulty in thinking about matters in which the sensory experiences generally have little apparent relation to what is being done to the subject, thus adding to the confusion.

We recognize that the traditional criteria for isolating and establishing the existence of a separate sense modality includes the factor of isolatable *experience* attributable to the activity of a specific body mechanism defined by the other three criteria. But we can now see that the failure to satisfy

this sensation criterion would be a poor basis for rejecting the vestibular mechanism as one of the sense modalities. The mechanism functions as do the other modalities in helping to relate the organism to its physical environment by being sensitive to a certain aspect of it.

Since the organism is constantly subjected to the compelling demands of the gravitational field regardless of whatever else he may be doing, vestibular functions, if they are to leave room for the organism to do other things, must be quite reflexive and automatic. Thus, in the vestibular sense, we have a sense modality that is quite different in many ways from the other sense modalities we possess. Much of its operation is not accompanied by the organism's self-awareness. We must avoid letting this lead us to the conclusion that vestibular activity is not a perceptual function. It has been pointed out elsewhere in this book that perception may be reflexive just so long as it meets the criteria in the definition for perceptual activity—namely, that perception is an immediate discriminatory kind of response involving sense organs.

While there have been differences of opinion as to whether there are unique sense experiences from rotation, movement, and position, Wendt (1951) holds to the tentative belief that there are. Various experiences that might otherwise be thought of as kinesthetic, such as the experience of sinking slowly while under water and the awareness of the direction of gravity while under water, are examples Wendt uses to support his belief. The significance of Wendt's examples lies in the fact that the body while under water is pressed upon in equal amounts from all directions. The findings of Griffith (1920), who has seemed to hold a position opposite to that of Wendt, must be given some recognition. His study involved introspections under several well-controlled conditions before, during, and following rotation of subjects in a revolving chair. He stated that he found dizziness to consist of a large number of processes that included ocular kinesthesis, tensions in neck and arms, pressure in the abdomen from the viscera, and pressure in the chest and head. In addition to these, certain vascular processes were attributed to supply a diffuse background of effects that colored the whole experience in a characteristic way. That Griffith could make these conclusions stems first from the nature of his subject's reports and second from the fact that under gravitational stress, such as induced in a revolving chair, body tissues are subjected to tensions that are neither tiny nor too usual.

Movement can also be experienced by moving the head while a visual target is stationary or when the target moves across the visual field or when the eyes are shut and the head is moved. Some of the experiences of movement, rotation, and posture are similar when the visual field is rotated or moved and when a sound source is revolved around the head. In the latter case, the sound may be experienced as standing still and the individual himself as revolving. It is obvious, then, that the experiences of bodily movement basically are not dependent upon vestibular stimulation.

If there are any unique vestibular experiences they are, to say the least, experiences of position, rotation, and rectilinear movement. It seems that the common element in perception of rotation at or near threshold is simply a vague "feeling" of rotation. Sometimes this has been described as a "swimming sensation." Griffith's study had to do with much more vigorous rotations, and there the experiences were complex and such as to lead to Griffith's description given above. The complex experience, however derived, was called dizziness. The same term is used when the visual field seems to whirl around the subject. A more technical but more inclusive term, *vertigo*, has come to be used nowadays. A common term covering a more comprehensive variety of symptoms is motion sickness. Vertigo may be only a state of confusion or uneasiness with regard to spatial position, movement, and so on. It seems to have autonomic components and, of course, an unpleasant feeling tone. Vertigo does not always require body movements to elicit it. Witkin's (1954) experiments with stationary subjects in a tilting room produced it. Hence it was produced without a kind of vestibular stimulation to account for it.

The vestibular apparatus

The bony labyrinth of which the cochlea, the auditory mechanism, is a part contains two sorts of structure, each containing the sense cells for the vestibular modality we have been discussing. The semicircular canals, the more familiar structures, are three canals lying at right angles to each other. These form a sort of three-dimensional coordinate system so that acceleration in any of the three dimensions will affect one or the other of them. Within the canals is a fluid called endolymph that circulates in accordance with the direction and amount of acceleration. At the base of each canal is an enlargement called the ampulla. In it are the endings of the nonauditory part of the VIII cranial nerve, called the vestibular nerve. Hairlike fibers of the nerve extend into a gelatinuous mass that is disturbed by accelerations and set up impulses that are conducted up the nerve to the brain. Aside from the normal stimuli incident to acceleration, the *ampulla* with its hair cells is affected by thermal impingements. Let hot or cold water be put into the ear; the result will be a series of nystagmoid movements of the eye, and the perceptual end result will be dizziness. The water put into the ears possibly becomes effective by setting up convection currents in the endolymph. Two other forms of impingement also induce vestibular responses: direct pressure and electricity.

Another portion of the vestibular structure is the *utricle,* which also contains sensitive hair cells and constitutes what is sometimes called the *otolith organ,* sensitive to static posture. It is thought by some to be slower in action than the semicircular canals. It is very difficult to isolate the actual functions of the canals and the otolith organ, for the various operations intended to produce stimulation not only may stimulate both of these organs

but include muscular stresses and tensions in the rest of the body that contribute to the overall sensory effect. For example, if one wishes to study the effect of posture, how should he do it? If he tilts the subject on a tilting board to which the subject is strapped, the whole set of mechanical pressures and pulls on body tissues is altered by each manipulation intended to affect the vestibular organs, thus complicating the matter considerably. One of the best ways would be to put the subject in a tank of water, for when a subject is immersed in water the pressures on the body are equal in all directions. But this is not so easy to put into practice, for one would have to fill the tank completely and put a lid on it so that tilting would not churn the water. If the tank was not full, the water would be disturbed by the movements of the tank and the subject would be moved within the water. This, of course, would disturb the equality of pressure in various directions and violate the conditions for which the water support for the body was sought in the first place. This description begins to make clear how difficult it is to study vestibular function in the most precise way.

Central pathways

The pathway conducting impulses from the labyrinth reaches the brain stem and the cerebellum (Fig. 13.2). In the brain stem, they end at the vestibular nuclei, specialized components of the reticular formation. From there, impulses are sent to the vestibulospinal tracts and the medial longitudinal fasciculi. Impulses are also sent to certain nuclei of the cranial nerves, especially those innervating the extrinsic eye muscles, by way of the medial longitudinal fasciculi and diffuse paths through the reticular formation. Connections with the visceral centers of the brain stem are also involved. Some impulses reach the cerebral cortex but their pathways are not definitely known. Their end points are either in or near area 41 in the superior temporal gyrus, the auditory area.

Nystagmus

The vestibular mechanism plays a role in the control of eye movements, along with the control mechanisms of vision, neck-muscle receptors, and the cerebral cortex.

One method of isolating vestibular effects is to move the subject in a rotating chair with the head fixed so as to avoid tonic neck reflexes. Vision is also excluded so that visual reinforcement or inhibition are excluded. In a small arc of passive head-body-chair rotation, the eyes manifest slow compensatory drifts interrupted by fast return movements. This is one form of nystagmus. The total compensatory movement is short of complete return so that the net effect is a rotation of about 60 percent of the head-body-chair rotation. The eye drift extends in time a little beyond the head-body-chair rotation, but its deceleration is more abrupt.

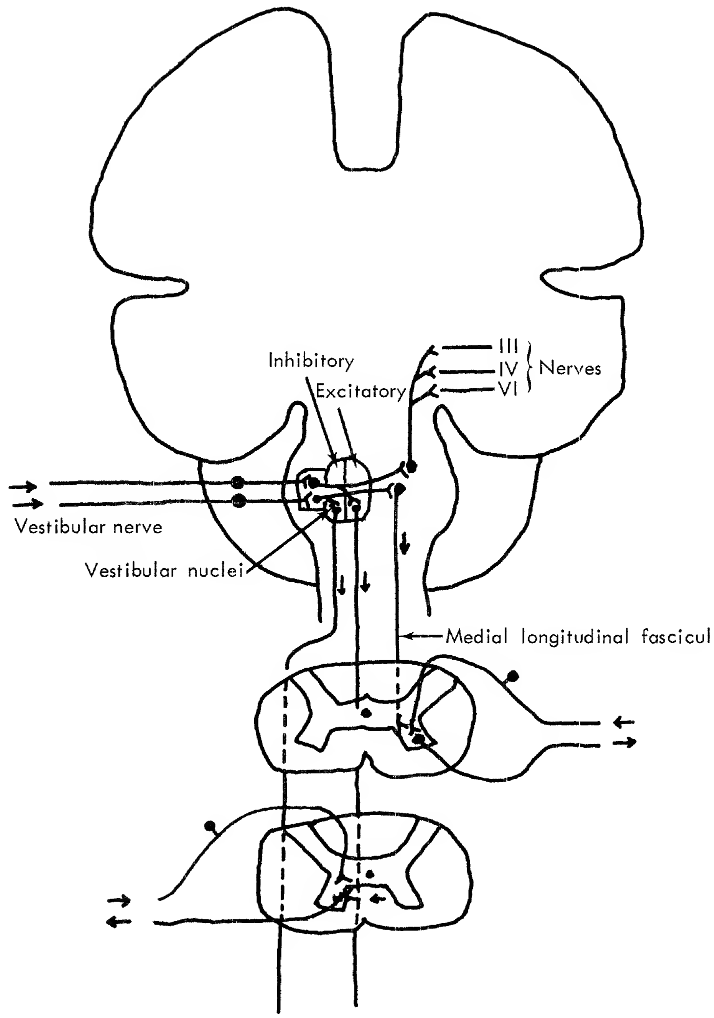


Fig. 13.2. Central pathways for the vestibular sense.

If one eye is open during rotation, the total slow phase is increased from 60 percent to 80 percent. If visual fixation is made on an object that rotates with the chair, the drift is reduced to about 5 percent.

If one rotates the subject at 180° per second, the shift from the stationary condition to steady rotation induces nystagmus. This consists first of a *primary nystagmus* and then of a *secondary nystagmus* in the opposite direction. The slow phase of the primary nystagmus lasts longer than the duration of the head-body-chair acceleration and lasts usually for about 35 seconds, during which time it slowly decreases. (This is called *post*

rotational nystagmus.) After this (the usually described nystagmus), the inverse or secondary nystagmus sets in and increases for about 80 seconds until the amplitude of the slow phase reaches about 5° per second. This nystagmus may not totally disappear for as long as 10 minutes. (For more details regarding nystagmus, see Dodge, 1923; Fischer, 1928; and Wendt, 1951).

Investigations with the human centrifuge

A number of studies have been made on human subjects by using a merry-go-round or centrifuge. Several large experimental centrifuges for this purpose exist in this country; they are very heavy and run with extreme smoothness. The accelerations and decelerations are smooth enough so as not to be detectable through the muscle and pressure senses as roughness or jarring.

A large part of the study of the vestibular sense consists in obtaining thresholds. Thresholds for angular acceleration, for example, have been worked upon quite carefully and have been obtained with the body in various positions, prone, upright, head down, and so on. Finding out just how sensitive vestibular and related mechanisms are provides a beginning understanding of perceptual response to gravity. Another important kind of study is ascertainment of the limits of tolerance for extreme accelerations. Part of the effects produced in such cases of course go far beyond effects on the vestibular mechanism to sheer mechanical effects on tissues and blood circulation.

Several centrifugal studies on vestibular function will serve to illustrate the sort of work that has been done in more recent years. One is Graybiel, Kerr, and Bartley's (1948) study on the thresholds for angular acceleration. A criterion of some sort had to be used. The "common-sense" criterion for a subject's sensitivity to speeding up or slowing down while riding on a centrifuge at or near its center would be the minimal feeling of being revolved very slowly. Various earlier investigators had used this direct experimental criterion. Graybiel and his colleagues used instead what has been called the "oculogyral illusion."

To explain this "illusion," let us say a subject is revolved while in an upright position (a sitting position, for example) with the axis of revolution through the center of the body and head. If this is done in the dark, so that there are no visual landmarks, the following effect can be produced. If the platform on which the subject is revolved carries a tiny light source, which the subject fixates as best he can, the light will not only revolve with the subject but will be perceived to lie straight ahead no matter at what speed the subject is revolved. But let the rate of body movement be suddenly changed and the light will appear to move to the right or to the left, depending on whether the change has been one of speeding up the revolu-

tion or of slowing it down. This visual effect is called the oculogyral illusion. We prefer to call it simply the oculogyral effect.

The problem of Graybiel and his colleagues was to determine how much the slowing down or speeding up of the rate of movement of the centrifuge had to be before the illuminated target appeared to move to the right or to the left. The authors not only controlled the rates of acceleration, positive and negative, but interposed uniform motion for necessary lengths of time between test periods for the canals to regain equilibrium. They controlled the lengths of test periods in order that they would be long enough to produce effects at minimal accelerations. The investigation disclosed that angular accelerations of 0.12° per second per second were necessary to reach human threshold detection.

There is a phenomenon in connection with riding on centrifuges that is both significant and interesting. You will recall that when you rode on a merry-go-round you leaned "inward," toward its center of rotation, once the merry-go-round got into motion. You gained the sensory impression that if you did not you would lose your balance and fall outward. Of course, the act of leaning inward was not a consciously calculated one; it was automatic or "reflexive."

If you were strapped into a chair fastened to the merry-go-round and facing the center of rotation, you would feel as though you were being tilted backward when the merry-go-round got into motion.

If the merry-go-round is in the dark and all you can see is a light, the source of which is fastened at eye level to the axis of rotation, the light will appear to rise as the merry-go-round accelerates. To get a better understanding of this, consult Fig. 13.3. The forces acting on the subject are indicated by CF and G, and the visual target is indicated by 1 and 2. Note that R is on a tilt from the perpendicular. This new direction of force is the perceptual "straight down" direction. Hence, if this is straight down, then the subject himself must be tilted back of "straight down." Consistent with the experience of being in a tilted-back position, the subject sees the light as above the old horizontal direction perceived to start with.

Experiments with a wave machine

Motion that may be imparted to the body is of various sorts such as pitching, rolling, and yawing (sidewise movement) of vehicles. Among all the possible motions, the up-and-down or vertical motion is one of the more effective forms on the organism. Aside from revolving chairs and centrifuges and swings, up-and-down moving platforms resembling elevators have been used for experimental purposes.

An arrangement used for imparting various rates and amplitudes of vertical motion to experimental subjects was employed by Alexander and his colleagues (1945). The device resembled a common passenger elevator

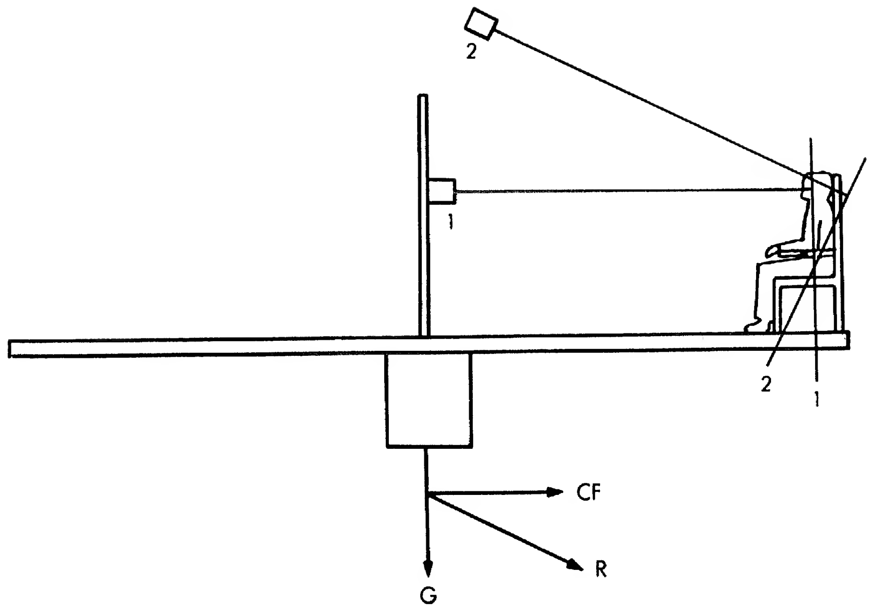


Fig. 13.3. Human centrifuge (merry-go-round), in which the posture of the subject is held upright while he is given a visual target to fixate in darkness. Rotation produces centrifugal force, CF, active in a horizontal direction. This and gravity, G, form a resultant, R. The visual target is perceived to be in position 2 during rotation. Also, axis of body seems to be tilted from position 1 to position 2.

and could be raised and lowered automatically by merely setting certain prearranged controls. It was called a *wave machine* because the motion was pretty much like an up-and-down wave motion. The investigation consisted in varying the amplitude of the vertical excursions from 4 to 10 feet (perhaps even more in certain experiments) and varying the rate of motion from 200 to 400 feet per minute. Variations were also made in the rate for reaching maximum motion—this is to say, the pattern of the wave was varied. Figure 13.4 gives some indication of what certain of the wave characteristics were.

Healthy young subjects were used, and the criterion for the effectiveness of the wave motion was whether or not sickness was produced within a limited time by riding in the wave machine. No subject was used for more than one trial, and so numerous subjects were required. The relations of motion sickness to time of day and to prior history of motion sickness of various sorts in the subjects were also studied. Finally, the question of whether manifesting motion sickness in the wave machine bore any relation to performance deficits in subsequent military tasks was also studied.

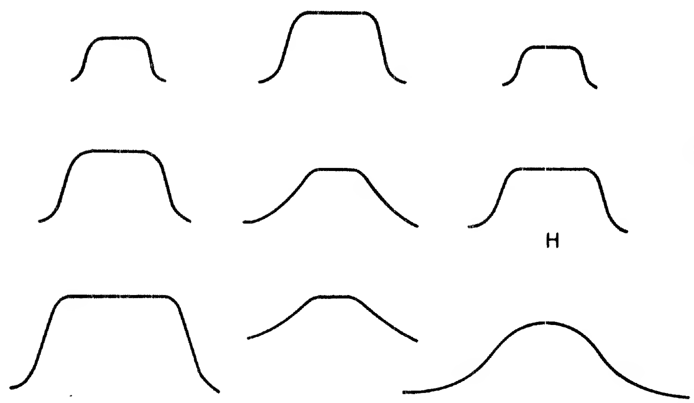


Fig. 13.4. Various patterns of vertical motion used by Alexander *et al.* to study motion sickness in a wave machine. (S. H. Bartley. *Beginning experimental psychology*. New York: McGraw-Hill, 1950, Fig. 68.)

The subjects were blindfolded during the ride and clothing was reduced to eliminate sweating to any induced by motion effects. Some of the subjects became sick during the tests and some did not. The degrees of sickness produced were distinguished by three categories 1, 2, and 0. Those who vomited within the limited time allowed on the machine were in category 2. Those reporting definite nausea or manifesting profuse sweating were in category 1. All other subjects were in category 0. Subjects assigned to 0 were not necessarily entirely unaffected. Some reported dizziness, headache, or slight nausea. Even pallor and a slight amount of sweating showed up in some cases.

The wave patterns used were not equally effective in producing sickness despite the fact that they all possessed the same energy content and that, at the midpoint of the excursions, the velocity was the same, namely 400 feet per minute. Figure 13.4 shows that wave H was most effective, even though it did not involve the most abrupt transitions from one rate to another throughout the excursion.

Motion sickness

Motion sickness is made up of one or more of the components headache, cold "sweating," feelings of muscular weakness, and experiences of malaise referable to various general parts of the body and head. The discomfort produced tends not to cease with the termination of body motion and in some cases may last several days. It is reported that deaf persons who show no other signs of vestibular sensitivity do not become motion sick. Apparently, some separation of acceleration and deceleration of move-

ment is highly effective in producing sickness. Short rapid phases of movement do not seem to be so effective. Such movements more nearly simulate ordinary head movements. Rotation in several planes at once or in sequence is most effective. Vertical motions, such as studied on the wave machine and occurring in rough airplane travel or in ships or in the rear seats of automobiles, are among the most usual causes of motion sickness. It is believed that lateral motion is quite ineffectual in producing sickness.

Obviously, the general attitude of the subject is a large factor. Unfavorable past experiences or convincing descriptions of the effectiveness of certain motions tend to induce genuine uneasiness in subjects, and this can very easily be enhanced by the imaginative processes that accompany stimulation in present situations. One of the outstanding observations has to do with the slightness of the physical motions that may induce sickness in the passively moved subject, as in contrast to the many varied and energetic motions that do not so result when the subject is in active motion. It would seem that no movement carried out by the subject himself is taken to be at all threatening, whereas movements induced by vehicles do carry a potential threat to the subject. Habituation to motion may occur in many cases: The rough motion of high-speed passenger trains becomes an insignificant feature in the everyday experiences of trainmen.

It should be obvious to the reader, once he grasps the details of the situations that produce motion sickness, that externally induced motion imparted to the human individual is a potential hazard that the organism through its evolution has had to develop means to cope with. Motion had to be detected and adequate and appropriate kinds of adjustment had to be possible in response to such motion. Of all the forms of external impingement that the organism encounters, there is none more compelling than motion due to loss of support from beneath or massive violent tossing. Such forms of mechanical disturbance might mean violent death, and the organism does not accept such forms of impingement with comfort and passivity. Even lesser forms have their untoward experiential effects and seem to call for avoidance. Passive submission comes only after a learning period, which may have, as one of its aspects, familiarization wherein the given motions are discovered not to be harmful after all.

Visual versus postural factors in perceiving verticality

It has long been supposed that when a subject is asked to adjust a visual target to the perceived vertical kinesthesis and the vestibular sense play a dominant role. If centrifugal force is combined with gravity, the subject would then use the somesthetic factors as determined by the resultant of the two forces just mentioned. Mach (1914) made this conclusion many years ago.

Koffka (1930) believed that when the visual and the somesthetic

frames of reference are brought into conflict, subjects use the visual in their perceptions. Wing and Passey (1950) believe that Witkin and Asch's (1948a, b) findings point toward a compromise between the two frames in the behavior of their subjects. Passey and Guedry's (1949) subjects tended to set the perceived visual vertical in line with the true, or gravitational, vertical in all cases.

Mann and his colleagues (1949) have shown that when a subject is tilted away from the perpendicular and is not allowed to use vision, he will not readjust himself to the true vertical if he is held in the tilted position for a number of seconds. The error in readjustment depends on both the time in the tilted position and the angular value of the tilt. The amount of tilt that is most effective seems to be in the neighborhood of 35°, and up to this point error increases with degree of tilt. Error increases with time in tilt up to about one minute.

Mann and Dauterive (1949) found that the uncertainty of a subject in perceiving the true vertical in posture is greatest when he is tilted only a few degrees. This range on both sides of the vertical was called the "arc of uncertainty." The reduction of proprioceptive cues tends to increase the arc of uncertainty.

Many years ago, Aubert (1886) found that when a subject viewed an upright visual target with his head tilted, the target seemed to be rotated away from the perpendicular in the direction opposite to head tilt. Subsequent refinements in observation have shown that when the head is tilted only slightly, the apparent tilt of the visual target is in the same direction as the head tilt, but when the head tilt is great, the effect noted by Aubert occurs.

Mann and Berry (1949) found that the mean error and variability in perceiving the visual horizontal are greater when the subject is in a tilted position than when he is vertical.

Witkin and his colleagues (1954) performed a number of experiments in which visual and postural factors were pitted against each other. One of the chief devices for making such studies was a tilting-room-tilting-chair combination. A small room, about seven feet in each dimension, was fixed so as to be rotatable around a horizontal axis (Fig. 13.5). The axis was through the center of the room and on the same axis the subject's chair was pivoted. This provided for lateral tilts of the subject to his left or his right as he sat facing the wall of the room, which could include tilts of both room and subject in the same direction, in either equal or unequal amounts, or tilts in the opposite direction, in either equal or unequal amounts. Both male and female subjects were used and found to behave differently. (The results depicting these differences are given in Chapter Sixteen. They are placed there owing to the suspicion that the differences may have come about through social development.)

The results that are relevant here pertain to the relative weights of the

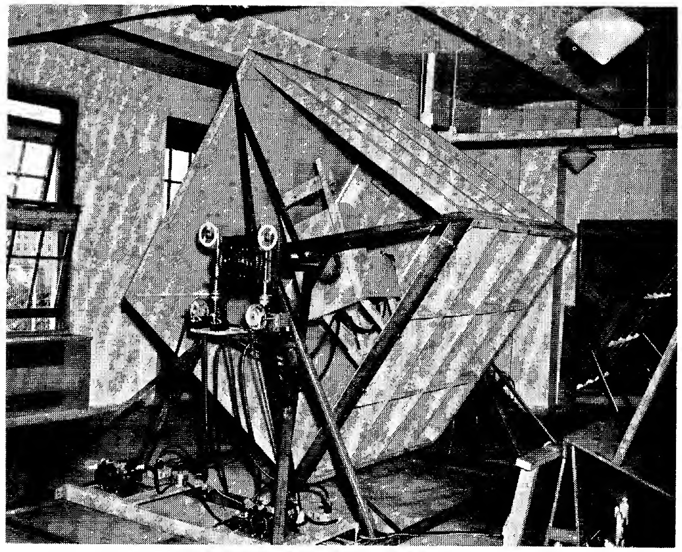


Fig. 13.5. The Witkin tilting-room tilting-chair apparatus. In this photograph, the chair is tilting to the left of vertical and the room is tilting to the right of verical. Little of the far wall of the room is visible. It and the floor, sidewalls, and ceiling constitute the subject's total visual field. (From Psychology Laboratory, State University of New York, by permission of Herman A. Witkin.)

visual and postural factors. One might suppose that even in the dark, where there is nothing involved but postural stimuli (those involving kinesthesis, vestibular activity, touch, and pressure), the subject would be certain that he is tipped when he is actually placed a number of degrees from the vertical, but this is not always the case. When a subject is confined in a chair whose arm and shoulder supports are adjusted snugly against him and he is tilted, the tactual and pressure experiences may mean simply pressure as applied laterally (horizontally) to him rather than perceived as indications of pressure due to tilt. Actually, such pressure resembles that induced by being squeezed against other persons in a crowd, and in line with this, these experiences evoke social connotations. In fact they may have curious, affective flavors.

The room in the Witkin experiments provides, of course, an all-encompassing visual field. Visually, the upright of the room is the convincing upright of the earth. If a plumb line is suspended from the ceiling of the room, it naturally conflicts with the expected positions that a plumb line should assume when the room is tilted. The visual appearance of the plumb line becomes different. In other words, whereas a plumb bob ordinarily looks as though it hangs by its own weight, it does not look that way when the room is tilted. It looks rigid, in deviating from what is perceived

to be the vertical. This appearance is, of course, an immediately and directly perceived one. Incidentally, this example is one of the many kinds that indicate the close parallelism between perception and what would be expected to occur through "reasoning." Both processes seem to follow the same logic, the same self-consistency.

Reflex activity

In connection with the activity of the vestibular mechanism, considerable reflex activity is evoked. This is made most apparent in animal experiments in which *righting reflexes* have been studied. Four sorts of righting reflexes are distinguishable.

A decerebrate mammal such as the rabbit, when held head-downward will, even when blindfolded, put its head in the same position as when its body is horizontal (normal position), exhibiting the *labyrinthine-righting* reflex. Changing the body in various positions still produces reflex movements whereby the head is put into the normal position. Such reflexes do not occur if the labyrinth is removed. One can faintly demonstrate these righting reflexes in the neonate. They develop in the very young human infant and are part of the child's ability to position head with reference to gravity.

Neck-righting reflexes, a second group, have to do with orienting the body with reference to the head. The body and the head can obviously assume a number of different positional relations to each other, and it is equally clear that the body must assume certain positions in the gravitational field to be effective. Hence, only certain combinations of head and body position will be effective, and reflex mechanisms sort out the effective combinations from the ineffective. These reflexes change body position so as to orient it properly with the head in certain positions with reference to gravity.

A third class is called the *body-righting reflexes*. If an animal with labyrinths removed is lowered to a surface while in a lateral position (on its side), the animal brings its head into a normal position with reference to the surface. The asymmetrical activation of tactile receptors on the two sides of the animal supposedly elicits body-righting reflexes. If an animal lying on its side is given symmetrical pressure stimulation on its two sides by pressing a board against its upper side, its head will have the "normal" position and will assume the lateral position in line with the body.

There are also *optic-righting reflexes*. In the higher subhuman species, the orientation of the head can be shown to be greatly controlled by vision. In such labyrinthinectomized animals freely suspended in air, the head is disoriented (may hang down) while the eyes are closed or blindfolded, but as soon as the animal is allowed to see, it fixates on items in the visual field and positions its head in relation to the field.

These righting reflexes are utilized by animals (a cat, for instance) in

quickly righting themselves with reference to gravity either in a fall or in cases where they are forcefully put into an ineffective position with gravity and the floor or other surface.

SUMMARY

This chapter dealt with the organism's mechanical relation and orientation to the earth and gravitational system. The organism's sense modalities for bodily movement, maintenance of posture, and manipulation were listed. Then the organism's muscle, tendon, and joint sense mechanisms were described.

The following were then discussed: (1) the tactual-kinesthetic perception of straightness, which was shown to possess some of the essential characteristics possessed by the visual perception of straightness while manifesting some definite differences. (2) The visual system was shown to play a role in tactual-kinesthetic perception. (3) The nature of tension and relaxation was examined. (4) Organic kinesthesis was discussed.

The second section described the vestibular sense, asking the question some have posed of whether there is a vestibular sense. The vestibular apparatus was described, and the distinction between the functions of the semicircular canals and the otolith organ was pointed out. The nature of nystagmus was also dealt with. Vertigo and motion sickness were also discussed. Following this, certain experimental investigations were reviewed, including experiments with the human centrifuge and the wave machine. Finally, experiments on the judgment of verticality following or during body tilt were described.

FOURTEEN

Taste and Smell Perceptions

Taste and smell are called the lower senses. This may be because the mechanisms for them are not as elaborate as are those for vision and hearing, and the consequent perceptions are not reducible to quantification in as highly particularized ways. Our interest in taste and smell is not confined to what can be said about mechanisms but extends to the roles these senses play in the economy of the organism as a person.

The taste (gustatory) sense and the smell (olfactory) sense are chemical and in the evolution of man have played the role of relating him to the chemical aspects of his environment. They help him select food and avoid harmful substances. In today's world they still play that role but to a relatively lesser degree. This is due in part to the development of higher modes of living and in part to the fact that man has erected a whole new universe of new chemical substances for which taste provides no clue as to their harmfulness or acceptability. Had the environment remained stable for a great enough time, these two senses might have provided an adequate criterion for what to accept and to reject.

Be all this as it may, tastes and odors play very important roles in the everyday economy of man. They are criteria of not only acceptance and rejection in foods but of other classes of stimuli. They are involved in the judgment of cleanliness of articles of use, living places, and people. To say that something stinks is to apply a strong and effective criterion for its avoidance. Odors possess very intimate characteristics that sights and sounds may lack. They have the quality of telling us something about hidden matters, something that sights and sounds do not reveal. Hence,

they provide experiences that are relied upon in ways that sights and sounds may not be.

Tastes and smells may have biological significance outside that of food-getting and food enjoyment. They are agents of sexual attraction and repulsion. What is more, the sensory impressions provided by them are very greatly subject to learning. What is now abhorrent may become attractive if involved in the proper conditioning process. To some, for example, the emotional impact of the olfactory combination of perfume, cigarette smoke, and the smell of alcoholic liquor on the breath is considerable and possesses a peculiar significance. Such result must have developed through the conditioning process, since one could hardly assign the impact to original pleasure of the smelling of smoke or of alcohol breath or even of perfume.

Odors are well remembered. Whereas one cannot be sure that a given color is identical to one he saw a few minutes ago in another context, one can feel sure that a present odor is the very same that he often smelled in childhood. This surely is not dependent upon a limitation in the kinds and varieties of odors that can be smelled. The stability represented may lie in the evolutionary priority of the sense, although we have no good way of testing such a notion.

TASTE

What is taste?

What we call taste proper and what in common-sense terms is called taste are not identical. The whole configuration of experiences localized in the mouth and attributed to what has been put into the mouth is called taste in everyday speech. The common man does not search for sense organs or classify them once they are disclosed. He only relates some outward operation and an experience that seems to accrue from it. Being more analytical and more precise, scientists search for sense receptors and try to relate the effective stimulus to the resulting experiences or other responses.

Taste then, according to the strict definition, is not the entire combination of experiences that ensues from placing something in the mouth. It is the group of experiences that ensue from something activating taste buds in the tongue and perhaps certain portions of the mouth wall. It is to be admitted that these are two very different sets of end results. Accordingly, we ought to have two terms to label them.

First of all, some substances placed in the mouth as food can also stimulate olfactory receptors in the nose. The perceiver is generally not able to distinguish what excites olfactory receptors along with taste receptors, giving rise to the common-sense failure to distinguish fully between taste and smell. The sheer mechanical properties of food and other substances has something to do with the overall experience produced and with

what is ordinarily called taste. Soft and hard materials taste different. Even the same kind of substance may taste different in two different textural conditions. The temperature of food has a great deal to do with its taste. Lukewarm and cold coffee differ greatly in the experiences they evoke from those of warm and hot coffee. Most soft drinks are very different when warm and when cold; some are scarcely acceptable when not iced.

A number of central nervous contributions are made to the sensory experience and acceptance of materials placed in the mouth. Whether the substance is considered clean makes a great difference to its taste. According to some points of view in psychology, this factor may be spoken of as affective or emotional, with the implication that it is an embellishment to perception, but we find it hard in many cases to disentangle it from other inherent aspects of perception. Many factors that contribute to gustatory end result are learned. Children characteristically resist sampling new forms of food, asserting that they do not like new substances that are offered. Once in a while, when the new substance is put into the mouth (and thus "tasted"), it is found to be palatable and pleasurable, but more often initial encounters are begun with an *a priori* aversion and learning may ensue. The question is whether the taste of the food changes as it becomes acceptable or whether the person changes so as to like what was first disliked. It is possible that both sorts of change occur. In some cases, more of one kind of change than the other may take place. We know of no careful, extended study on this point.

Resolving a dilemma

It would be desirable if the common-sense and scientific discrepancy in what is called taste could be resolved. It seems very artificial to confine taste to the experiences mediated by taste buds of the tongue. Yet it would be a great departure from the principles used to classify sense modalities if all the elements in the experience that is produced by putting something into the mouth were included. Simply choosing an additional word so that every item has a label will not resolve the dilemma: It will not do simply to have one word for the experience mediated by taste buds and another for the overall experience of putting something into the mouth. Both experiences have enough in common to merit being kept together in a single category.

Another possible way of resolving the matter is to revamp the logic and terminology of sensory classification. It will be recalled that certain criteria have long been used to determine which sense experiences are to be classified together and thus determine how many categories there are. Among the criteria used to set up a new sense modality are (1) establishing a unique set of experiences, (2) proving a separate set of sense organs, (3) finding a unique kind of stimulus, and (4) showing a specific afferent sense pathway. With these criteria men now confine taste to the results

mediated by taste buds. Other qualities of "taste" come from other modalities.

It would be possible to revamp this outlook and deal with experiences and other reactions as they seem to fall into broad functional classes. For example, one of the organism's functions is maintaining body equilibrium. In the case of taste, the function would be that of appreciating what is put into the mouth for acceptance, rejection, and so on. This broad functional classification of human interactions with the environment would possibly run into various troubles no less perplexing than the problem itself. Even the beginning student of psychology ought nevertheless to be aware of the problem and of its difficulty and the possibility of resolving it by a radical remodeling of the classification system of all perceptual performance.

The foregoing remarks are in the original edition of this book. Since its appearance, Gibson (1966) has published his work on perception and has, in effect, put into expression some of the things just suggested. In Chapter Seventeen, you will be introduced to his outlook on the relation of specific sense modalities and perception.

Taste receptors

Taste receptors are located primarily on the tongue and give rise to four perceptual qualities: salt, sweet, bitter, and sour. The areas of greatest sensibility are the tip, sides, and rear of the top surface of the tongue. The middle of the top surface is quite insensitive for taste production.

The receptor organs are called *taste buds*. They are made up of a group of cells, one to two dozen in a cluster. The sensitive cells are spindle-shaped. The receptor cells are constantly degenerating and being replaced by new ones (Fig. 14.1). Taste buds are grouped in papillae of four forms: *fungiform, foliate, circumvallate, filiform.* The circumvallate papillae are surrounded by a "moat" into which the taste pores open. The papillae contain many buds, and the count remains about the same until late maturity, when the number reduces.

The gustatory receptors (the cells in the taste bud) serve only to generate the impulses sent to the central nervous system. Nerve fibers arborize and terminate on the receptor cells, and it is these fibers that carry the impulses to the brain. Since the receptors change chemical energy supplied by the impinging substance to neural excitations, they are said to be *transducers;* the nerve fibers are called gustatory afferents.

The tongue and mouth are supplied by four cranial nerves. The facial (VII nerve), the glossopharyngeal (IX nerve), and the vagus (X nerve) are involved in the sense of taste. The trigeminal (V nerve) is concerned solely with skin functions; even so, it is involved in taste, since it has to do with the tactual patterns we have already said are a part of the overall "taste" experience. Taste is not represented in the cortex by a special primary receiving zone (or projection area) with exclusive gustatory functions.

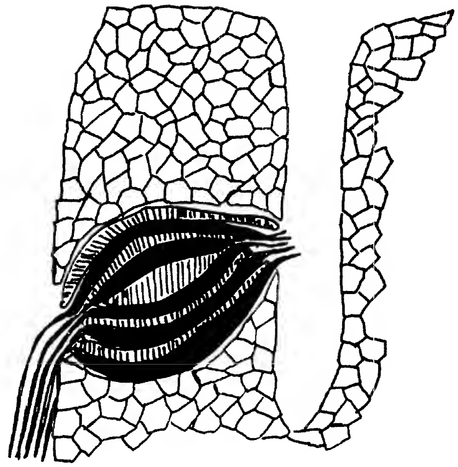


Fig. 14.1. A taste bud. It is made up of two sorts of cells in a capsule: the sense cells (shown in black) and the supporting cells (shown striped). The sense cells terminate in hairs that project into a slot-like cavity or "moat."

Pfaffmann (1959) stated that it is certain from neurophysiological evidence in animal experiments that taste receptors are not always classifiable into the four basic types corresponding to the taste qualities of sour, salt, bitter, and sweet. Individual fibers are differentially sensitive to substances. He suggested that this is probably because of functional differences at different places on the cell membrane. Thus, the overall resultant pattern of sensitivity stems from a cluster of separate sensitivities. This cluster differs from cell to cell.

Pfaffman, recording from single fiber preparations in the cat, found the species to have three types of gustatory fibers. One type of receptor was activated by acids, one was activated by acids and quinine (our bitter-producing substance), and another was activated by acids and sodium chloride (our salty-tasting substance). Increasing the concentration caused a rise in frequency of impulse discharge up to a limiting value. Beyond this, greater intensities were no longer effective. Each of the three types of fiber showed a range of thresholds, and response consisted in a slowly adapting (a diminishing) sequence of impulses.

Species differences in response to gustatory stimuli have been shown by differences in recorded neurophysiological responses. Afferent discharges were found to be quite similar for HCl in the cat, rabbit, and rat, but marked differences showed up for NaCl (table salt). The lesser magnitude of response to quinine and sucrose may indicate fewer sensitive fibers in the animals. The cat shows the best response of the three to quinine and the poorest to sucrose. It is just the opposite with the rabbit, while the rat responds equally well to both.

Since Pfaffmann's records were obtained from nerve fibers rather than receptor cells themselves, it is appropriate to ask whether fibers may each serve several receptor cells, each of which subserve different taste qualities. This is possible anatomically, since two or three fibers generally serve a single taste bud. The question seems to be answered by the work of Kimura and Beidler (1956), who recorded from single receptor cells and obtained the same results as Pfaffman's. Therefore, it is likely that the patterns of sensitivity depicted by Pfaffmann represent receptor cells.

Taste stimuli

In order to be tasted, usually a substance must be soluble in water. Regardless of the physical state of the substance to begin with, if it dissolves to some extent in saliva, it is effective. The effectiveness of the impinging substances depends on several factors, such as degree of solubility, concentration, ability to ionize, temperature, and chemical composition. From all the variables we know, there are still only the four elemental taste effects, if we keep to the activation of taste buds.

Common table salt (NaCl) is the standard stimulus for saltiness, and all other substances are compared with it for that quality. Both of the ions ($Na+$ and $Cl-$) are responsible for saltiness. The chloride ion ($Cl-$) can of course be combined with other elements and positive ions such as potassium, ammonium, calcium, lithium, and zinc. All the resulting compounds taste salty but not qualitatively the same, indicating that the positive ions as well as the chloride ion must be factors.

Some substances have effects in addition to stimulating taste buds as such; some are astringents and thus produce peculiar mechanical effects on tissue and activate the cutaneous sense. The salts, such as sodium and potassium, are molecularly light. With heavier elements the salty taste tends to shift to bitter. Cesium chloride, a substance with high molecular weight, is sweet. Not all heavy halides (the group of elements that includes chlorine, fluorine, bromine, and iodine) are sweet but tend to be bitter. Hence, what we know about chemicals and the tastes they produce does not form perfectly simple relationships.

Sourness is a result of ionization, too. The substances that produce it provide acid dissociation and liberation of hydrogen ions. The common inorganic acids such as sulphuric acid, hydrochloric acid, and nitric acid are similar in taste when matched in concentration. Organic acids do not resemble each other completely in their sour taste, and thus it is deduced that the concentration of the hydrogen ion is not exclusively responsible for their tastes. Perhaps such chemical compounds affect more than a single sort of taste receptor and in that way bring about a taste complex.

The stimuli for bitter and sweet usually do not seem to be ionic. Among the most common bitter-taste producers are the alkaloids, such as

nicotine, strychnine, quinine, and brucine. These seem to be effective in molecular rather than ionic form. The commonest ionic solutions that give rise to bitterness are magnesium, iron, silver, and iodine.

The sweetest-tasting substances are the complex molecules of the sugars and similar compounds used as sugar substitutes, such as saccharine. Some substances are supposed to be thousands of times as effective as ordinary cane sugar, but reactions to them are not as constant and predictable as they are to cane sugar.

There is a close connection between bitter and sweet, as evidenced by the result of slight changes in chemical composition needed to shift the sensory effect from sweetness to bitterness.

Some chemicals injected into the body through the blood stream give rise to taste. One is nicotinic acid. The physician can pretty well predict the number of seconds from the instant of injection, let us say in the wrist, until the patient will experience a tingle and a metallic taste at the tip of the tongue. Taste can be aroused also by electrical stimulation supplied to the tongue. If the current flows in one direction, the taste is sour; if the current is reversed, a very different taste results. Geldard (1953) describes it as soapy and somewhat burning. The frequency of alternating current manipulates taste. With low frequencies, sourness is elicited; with high frequencies, the taste tends to be bitter.

The complex tastes of many substances can be duplicated by combinations of other substances that elicit the four elementary tastes. The salt-sour-bitter quality of potassium chloride, for instance, can be duplicated by a certain mixture of sodium chloride, tartaric acid, and quinine.

Pointlike stimulation of areas of the tongue indicates that sensitivity to stimuli producing the salty quality is greatest on the tip and sides, that sour is better evoked along the sides than at the tip, that sweet is easiest to evoke on the tip, and that bitter comes out best with the appropriate stimuli on the back of the tongue. (See Fig. 14.2.) It seems that in some of the various papillae there are combinations of the four elemental types of taste buds.

Individual nerve fibers have been found to supply more than one taste bud. Certain fibers have been isolated in the cat that respond to the application of only a single substance, for instance, an acid, whereas two other types of fiber were also found by Pfaffmann (1955). One of these responded to acid and salt stimuli, and another responded to acid and quinine (bitter). He did not find any responsive to sugar (see page 383).

Taste thresholds

Not all individuals taste the same qualities from a substance put into the mouth. In general, there must be considerable likeness, but in some cases there is an unquestionable difference. First of all, some people are

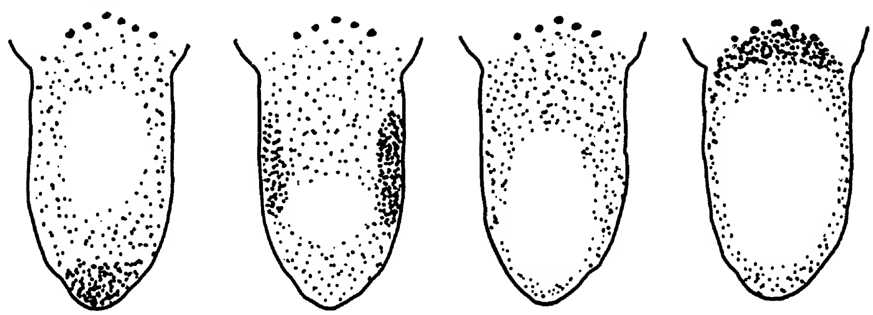


Fig. 14.2. A plot of the gustatory sensitivity of the tongue, using Hänig's and Henning's findings combined.

virtually "taste-blind" to such substances as phenylthiocarbimide while others taste it as bitter. Insensitivity seems to be inherited. The differences in threshold for the tasting of other substances may be based upon differences in the acidity of the taster's saliva. It has been reported that during pregnancy certain taste thresholds are raised. This is often true for sodium chloride and for acid-tasting substances.

Bornstein (1940a, b) found that in general the following substances in the following concentrations gave the results indicated. Four grams of sucrose per 100 cubic centimeters of water were easily recognizable. Ten grams tended to taste quite strong, 40 grams very strong. Table salt was easily perceived with 2.5 grams per 100 cubic centimeters; solutions of 7.5 grams were medium strong; double this concentration was very strong. Quinine monohydrochloride was easily recognized as a bitter taste when only 0.075 gram was placed in 100 cubic centimeters of water. One-half gram was moderately strong, and twice that concentration was very strong. The sourness of citric acid was easily detected when one gram was placed in 100 cubic centimeters of water. Five times this concentration was medium strong, and double the strong concentration was very strong. These concentrations were used for testing patients for taste deficits.

As was earlier pointed out, temperature has considerable influence on taste end results. The best extensive work on the effect of temperature was performed by Hahn and Günther (1932). With the device they used, the tongue area under investigation was brought to the temperature of the taste stimulus to be used and was maintained there. Starting with a temperature of 17° C (about 63° F), raising the temperature of a weak solution of dulcin (a sweet-tasting substance) caused the threshold for it to drop until a temperature of about 34° to 35° C was reached. At about 36° or 37° C (95° F) the threshold began to rise again, indicating that the

sweet taste could be detected more easily as the temperature rose from around 17° C to 37° C.

Sodium chloride at about 17° C had initially a lower threshold than the acid solution just mentioned, but the threshold rose in a virtually linear fashion up to the limit of the range tested (42° C, or 107.6° F). Hydrochloric acid remained about the same in taste-producing effect over the entire range tested.

Quinine sulphate, which at the lower end of the temperature range tested was the most effective of the solutions used, soon rose slowly in threshold, then more rapidly as temperature was raised, and ended at being about as effective as sodium chloride at the upper limit of the temperature range.

Pfaffmann (1951) pointed out that such complex effects cannot be interpreted as simple chemical reactions between substances and taste cells, for most chemical reactions are magnified as temperature rises. Some of the end results just given run in the very opposite direction. Of the four substances mentioned, dulcin alone behaved this way, and it did so only over part of the range.

We have already pointed out the taste effect of direct venous injections of nicotinic acid. Other similar effects have been taken to indicate that blood composition is a factor in taste, though this has not been fully substantiated, even while certain food preferences in animals, under certain conditions, bear on the matter. Adrenalectomized animals, rendered salt deficient by the operation, manifest definite preference for salty foods and water. On the other hand, sensitivity for sugar is reduced in states of hypoglycemia (sugar lack). In the same subjects, sensitivity to the other taste-producing substances is left unaffected.

The sense of taste adapts quite fully. Adaptation has been studied by Dallenbach and his colleagues in precise experiments on restricted portions of the tongue. Adaptation is proportional to the strength of the solution used. A large number of salty taste-producing substances tested were found not to interfere with each other in their adaptations. That is, adaptation to one substance of the group did not affect sensitivity to the others. This poses the question of whether there is more than one type of salt receptor. All acids were found to affect each other, that is, to cross-adapt. Certain sweet and bitter tastes cross-adapted, but others did not. A possible conclusion from the failure of cross-adaptation is that adaptation and stimulation are two separate processes. This was suggested on the assumption that there are not as many kinds of salt receptors as salt-producing stimuli that do not cross-adapt. There were twenty-four such substances in the experiment. On the other hand, if stimulation and adaptation are two separate processes, one cannot deduce the nature of stimulation from adaptation findings.

Taste scales

Understanding a process is promoted by success in scaling the end result in relation to the quantitative features of the stimulus. Lewis (1948) worked on the scaling of the elemental tastes somewhat in the manner of those who have scaled loudness and pitch of sounds in sones and mels and weight-lifting in wegs. He found that the classical scale units (JNDs, just-noticeable differences) differed in size in different portions of the stimulus scale.

Beebe-Center and Waddell (1948) made cross-comparisons between salt and sweet. This was possible because the subjects were able to select a solution of a salt stimulus that would be as salty as sucrose was sweet. The scales for all four elemental tastes were integrated. They then defined the unit of taste as a *gust*, the taste strength of a 1 percent solution of sucrose. Gusts applied not only to strength of sweetness but also to strengths of sourness, bitterness, and saltiness.

In Fig. 14.3, gusts, in logarithmic terms, are plotted against the concentration of the taste-producing solution (log grams per 100 cubic centimeters of water). It will be seen that the strength of taste production of

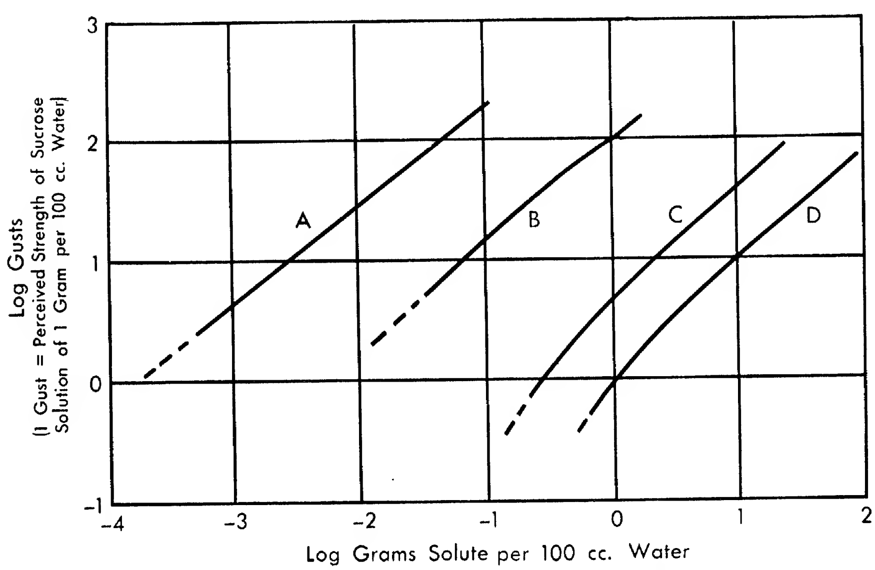


Fig. 14.3. Relation of gusts to concentration of solution. Curve A is for quinine sulphate, B for tartaric acid, C for sodium chloride, D for sucrose. (J. G. Beebe-Center & D. Waddell. A general psychological scale of taste. *J. Psychol.,* 1948, **26**, 517–524, Fig. 3.)

quinine (bitter) is greater than the strength of tartaric acid (sour), and that the acid is stronger in taste than sodium chloride, the standard of saltiness. In turn, sodium chloride is stronger than sucrose, which is sweet-tasting. The slope of the curves for each quality is nearly the same.

Beebe-Center (1949) went farther and examined common food substances with the gust scale. The scale data were obtained by the fractionation method. There is some doubt as to the full validity of what was used as "half-value." There has also been some suggestion that adaptation might have distorted the results. Despite these criticisms the scale, as a standardization, has some value.

Other psychophysical studies of taste

Although not much success has attended efforts to relate taste qualities to chemical structure of substances, certain psychophysical investigations have succeeded in scaling tastes such as sweetness. For example, two sweet-tasting substances, sucrose and crystallose, were scaled in terms of concentrations of solutions needed to give a series of JNDs in sweetness between the two substances. It was found that equal numbers of steps above threshold were not equally sweet. For example, a concentration providing for six steps (JNDs) above threshold for sucrose required nine steps to match it in sweetness with the other substance. As concentrations of the two substances were made greater, the crystallose became relatively less effective than sucrose in producing sweetness when applied to the tongue. This was true also for certain other substances. Some substances increased slightly in relative sweetness as concentrations were increased. Investigations studying the possibility of scaling sweetness have indicated that JNDs for sweetness vary in their magnitude as concentration increases.

Foods, personality, and status

It appears that tastes (and odors) involve stronger effective aspects than perceptions in other modalities, excepting pain. The four taste qualities are not alike in the direction of their effects, as is indicated by strong bitterness being unpleasant and strong sweetness generally pleasant. Of course, psychophysical findings must be tempered with everyday observations contradicting them, for these sense impressions are open to much variation through learning. It is possible that taste and smell are open to wider variations in conditioning than any of the other sense modalities.

Food aversions and cravings are used for diagnostic purposes in certain modes of professional psychotherapies. High-anxiety subjects have been found experimentally to have a greater number of food aversions than low-anxiety subjects.

It is possible that a great many studies in social perception could be made by using taste substances as stimuli. This has not been done as yet.

SMELL

The olfactory sense cells in the nose are often involved when substances are taken into the mouth. The senses of taste and smell function in indistinguishable combination in many everyday situations. We often ascribe to the sense of taste the functions that belong, at least in part, to the sense of smell. Substances evoking one of the four elemental taste qualities alone do not involve the sense of smell. But the situation is very different when common food substances are to be rightly identified and fully appreciated. The full flavor of butter, fruits, coffee, meats, and so on depends greatly on the sense of smell. It is startling to find that one cannot find taste differences between raw potato and apple when the nose is stoppered and the eyes are not used. The chief differences are mechanical, that is, dependent upon the hardness and textural qualities of the substances rather than taste. Many other substances fail to produce their usual tastes and instead provide only weak sweet, sour, or bitter tastes when the sense of smell is prevented from functioning. Such substances as peppermint, onion, cinnamon, all of which are thought to be quite strong in taste, elicit little taste when smell is precluded.

A good substance for gauging three major kinds of effect on oral and nasal tissue is ethyl alcohol. The modalities of smell, taste, and pain can be tested with varying concentrations of this one substance. For example, smell can be evoked by concentrations 20,000 times weaker than needed to evoke taste. Concentrations three times as great as needed for taste produce a "cutaneous" burning effect.

Smell receptors

The sense cells for smell are contained in two small patches of epithelium, the *olfactory epithelium* high up in the nasal passages. The cells are not in the main passageways for the air used in breathing. To reach them, the air must be deflected. In reaching the receptors, it is moistened and cleaned of dust.

The substance reaching the sense cells must obviously be airborne and in a gaseous state. Not a great deal of the substance need reach the cells, as is illustrated by the fact that only four one-hundred millionths of a milligram of ethyl mercaptan in a liter of air is enough to evoke its perception. While this sounds like an extremely small amount, a single sniff of the air so diluted will contain several million molecules. The olfactory epithelium is so inaccesible that research is extremely difficult.

Methodology

The matter of methodology has always been a problem in the study of olfaction and a series of methods has developed. One of the better known devices in the early days was Zwaardemaker's olfactometer. The curved end of a tube was placed in the nostril. Over the opposite end of this tube fitted a larger-bored tube containing the odor-producing material. Sniffing drew air over the material and into the nose. In the 1930s the Elsberg blast injection bottle was devised to overcome some of the faults of this method. The bottle contained the odor-producing material, and a hypodermic syringe leading to a tube reaching to nearly the bottom of the bottle forced a known amount of added air into the bottle. Two tubes leading to the nostrils were held shut by a pinch clamp until the extra air was added to the bottle. When the pinch clamp was released, air went into the nostrils.

Wenzel (1949) used a still different stimulus system. The subject's head was placed in a plexiglass chamber into which a constant stream of purified air was blown. Odorous material of known amount was added to the flow system so that the concentrations could be specified in molecules per unit volume of air. Still other devices are being used, but the described ones indicate the most common methods.

Classification of olfactory qualities

The elemental gustatory qualities are few and definite. The same is not true of smell qualities. Investigators have attempted to discover natural classifications to provide a kind of rhyme and reason to the very complex situation. The oldest classification we know about was made in the middle of the eighteenth century by Linnaeus. It had seven categories: aromatic (carnation), fragrant (lily), ambrosial (musk), alliaceous (garlic), hircine (valerian), repulsive (certain beetles), and nauseous (carrion).

Just after the turn of the nineteenth century, Zwaardemaker (1925) began his study of odors and continued it for thirty years. He expanded the classification just given, adding ethereal and empyreumatic as a result of the expansion of organic chemistry with its many new substances. Zwaardemaker also divided the nine classes into a number of subclasses. His contemporary Henning (1916) developed during the later part of the Zwaardemaker period a very different classification of only six categories, occupying the corners of a prism (Fig. 14.4). They were fragrant, ethereal, resinous, spicy, putrid, and empyreumatic (burned smell).

The findings that gave rise to Henning's prism ran somewhat as follows. A group of substances that seemed somehow to belong together according to smell was examined carefully for the quality complex that

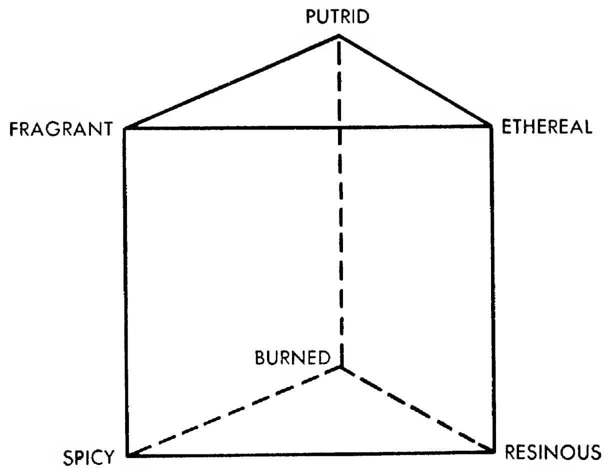


Fig. 14.4. Henning's odor prism.

each presented; and a sort of progression emerged. Starting for example with sassafras, he might have come next to nutmeg, then pepper, then cinnamon, with a seeming progression in spiciness in the order mentioned. But as other substances of this general group were examined, a new quality emerged and the spiciness receded. Speaking geometrically, it was as if a corner had been reached and turned. Cassia, cloves, bay, and thyme seemed to represent a new progression. A corner was again reached; and since there are four corners, and the progression turned upon itself to make a closed cycle, the geometrical form taken to represent it was a square. It could have been a rectangle or some other quadrilateral figure instead. When odors that did not seem to belong in the progression, or loop, were found, they had to represent dimensions (or progressions) running off at angles to the first one. Some odors studied did not belong in the surface just mentioned, so the geometrical figure had to be a three-dimensional one. Henning ended up with a five-faced prism along whose edges, he believed, all odors would find a place. Pure odors lying between two other odors along an edge might resemble them but cannot be synthesized by combining them. Experts as well as laymen have taken some cognizance of this fact.

MacDonald (1922) and Findley (1924) independently attempted systematic investigations to test a number of odors on the basis of Henning's prism. The stimuli they used for Henning's "primary" odors were (fragrant) oil of jasmine; (ethereal) citral and oil of lemon, respectively; (resinous) eucalyptol and turpentine, respectively; (spicy) anethole and cinnamon, respectively; (putrid) thiophenol and hydrogen sulphide, respectively; (burned) pyridine and oil of tar, respectively.

The procedure was to present one standard or primary substance to the observer, then one of the many secondary substances to be perceived, and then one of the other standard substances. The task of the observer was to tell which of the two standards the secondary or comparison substance smelled more like. The report was presumably to be based on odor rather than intensity or some collateral quality such as coldness or bitiness. Each of the many comparison substances was compared to all six primary or standard substances during the overall procedure. It happened that, even in this attempt to be systematic and orderly, the comparison odors were highly variable in their perceived similarities and tended to be like various standards in turn. This sort of result might be interpreted as requiring the placing of substances *within* the prism instead of only along the edges between the primaries at the corners. Henning had insisted, on the contrary, that the prism is empty and does not contain internal positions representing odor relations to each other. He declared that the prism was an odor prism and not a stimulus prism. Various odors do change—that is, any given substance is likely to be smelled differently from time to time—but this was not to lead to the use of the space within the prism for odor designations.

MacDonald (1922) used only the four primaries contained in the FERS face of the prism, the fragrant, ethereal, resinous, and spicy-smelling primary stimuli. He used eleven stimuli and asked his observers to place the separate odors where they seemed to belong in the square or along its edges. The comparison stimuli used supposedly had no resemblance to the putrid or burned odors. For some stimuli, the placement could be accomplished but with difficulty. One curious result was that a given odor might seem to belong in the square but not resemble well all the corners. Some odors seemed to lie along the diagonals of the square. Nutmeg and geraniol lay along the ES diagonal, for example, while not always resembling E or S. The logic of the prism would require that the middle of the ES diagonal would be also the middle of the FR diagonal. Anything at this point would resemble F and R. It turns out, then, that the actual olfactory results do not fit the prism either as used by Henning or by MacDonald, who allowed the interior to be used. One modification of the prism would be to alter its faces from squares or rectangles to certain quadrilaterals, although this does not look too promising.

Substances may smell somewhat the way they taste, once the perceiver takes it that he is smelling instead of tasting. For example, substances may smell sweet or sour. Substances may smell prickly, warm, or cold. This is not surprising, because the nose is supplied not only with olfactory epithelium but also with the cutaneous senses of touch, pain, and temperature. Sharp, prickly, or biting odors obviously involve the sense of pain: Ammonia and chlorine evoke pain, whereas menthol stimulates cold receptors.

Woodworth and Schlosberg (1954) stated that the presence of non-

olfactory sensations necessitates the revision of the classification of odor qualities or at least an experimental reexamination to factor out the nonolfactory components. The whole FERS face might coalesce into a single class if pungency (pain sense), freshness (cold sense), and sweetness (taste) could be eliminated. The system of odor qualities might be simplified, or certain fundamental odors that fail to stand out when blended with nonolfactory components might be disclosed.

Hermann (1926) found in trying to use Henning's prism that his observers balked. Some of them declared that the Henning choices as fundamentals were no more primary than certain other substances that could be given other labels. Among the items in this category were camphor and mint.

It might still be that a reworking of primaries would accomplish the end result expected of Henning's six groups. Actually, all faces would not need to be quadrilateral. Some might be three-sided, some five-sided. It cannot be said that the idea of using a geometrical figure to represent systematic relations between odors (not stimuli) has been tried to the point of logical discard. The idea that all faces need not be of the same number of sides is borne out by the fact that at present some odors have been found not to belong at all to Henning's prism. In Hazzard's study (1930), for example, various dimensions of olfactory experience not commonly brought out were examined. These were heaviness-lightness, looseness-tightness, smoothness-roughness, softness-hardness, dullness-sharpness, liveliness-inertness, thinness-thickness, brightness-dullness, surfaceness-deepness, and smallness-largeness. It was found from Hazzard's observers that spicy odors tended to be sharp, lively, and bright. Putrid odors were dull and inert. Burned odors were hard, tight, and heavy. Fragrant odors were light, soft, and loose. Woodworth and Schlosberg suggest that the texture components reported for odors suggest the participation of the cutaneous sense in "smell."

Interaction of olfactory stimuli

It is very often said that one odor may mask another. If taken literally, the statement would assert that one sensory experience may mask another. It must be remembered that a masked experience is no experience at all. It is gratuitous to infer that the masked experience exists but is simply covered up. Instead of implying that there are two experiences, one entirely covered up and the other not, it should be recognized that there is only one experience. All that should be meant is that two olfactory impingements, each of which produces an experience when operating alone, may, when operating concurrently, interact to produce the experience expected of one of them alone. The illogic of common speech shows up in its most extreme form when masking is talked about with its usual connotations: Something

is implied to exist that does not exist. If there is any case in which this does not work, it is in sensory experience. Sensory experience is not a matter of imputation, inference, or conceptualization. An experience, to exist, must be an experience. That which is not experienced does not exist.

When two olfactory stimuli are presented together in time, any one of six results may ensue.

1. The most frequent is the blending of the two odors, the production of a single odor having some properties of both and, possibly, some new characteristic. In what is called a blend, one may detect the resemblances to the separate odors produced by the same two stimuli when they are presented independently in time. Substances that produce end results more nearly alike—that is, in which it is most difficult to isolate one or the other of the two components—produce the best blends. It is possible that increasingly precise experimentation will find this conclusion not strictly true in all respects.
2. When stimuli yielding very dissimilar odors are presented together, the two odors are both produced, first one and then the other being the center of attention.
3. When one odor is presented to one nostril (dichorhinic stimulation), the results are somewhat as in binocular rivalry: The two odors are smelled in alternation. Whether this is a compelling result from some basic perceptual standpoint or merely a shift of attention is not certain. Some declare it is the latter and should not be called rivalry.
4. It is also declared that two odors may be experienced simultaneously and yet separately. They may appear, according to Woodworth and Schlosberg (1954), as a chord of musical tones, or as two separate but unrelated odors. Henning (1916) declared that this last result is possible only with dichorhinic stimulation, whereas Skramlik (1925) stated that it can occur with either one or two nostrils. In fact, Skramlik stated that all so-called dichorhinic effects can be obtained with a single nostril.
5. One odor may mask the other entirely, an effect already discussed.
6. One odor may neutralize another. This, too, must be an effect taking place below the level of consciousness so that nothing appears in consciousness as an odor. There has not been complete agreement as to whether neutralization can occur, but the authorities who have declared it possible include those who have never been surpassed in carefulness.

CONCLUSIONS

For a long time the literature on gustation and olfaction was occupied by studies on the classification of odors and the attempt to relate odors to specific classes of chemicals. More recently there has been in addition to this a growing number of studies on the anatomy of the taste organs and

the neural pathways for these senses and the kinds of neural responses evoked by various chemicals. The findings have shown that the four-taste classification has not been paralleled by four types of receptors and four types of discharge. Various theories with reference to the quantitative relation between impingement and response have also appeared. While not a great deal can be said as yet, the outlook is promising for a far better understanding of the mechanisms underlying taste and smell.

Hazzard's study (1930) comes closest to examining the role of olfaction in the economy of the individual. At least, it possesses possibilities in this direction. When it can be said that an odor is more than something sweet or fragrant but possesses qualities belonging to other sense modalities, one broadens the significance of the olfactory experience and shows how olfaction plays a broad role in the affairs of the individual.

SUMMARY

This chapter dealt with the so-called lower senses of smell and taste. Following some introductory remarks, the sense of taste was introduced by asking, "What is taste?" There are two quite different definitions, depending upon whether one uses the overall organism-centered viewpoint or the four analytical criteria traditionally involved in isolating sense modalities. A way of resolving the matter was offered.

Taste receptors were described, and their locations were pointed out. The nature of the modality's response to various common stimuli used in experimentation was described. This involved reporting on a number of definitive investigations aimed primarily at understanding the body mechanisms involved.

The fact that taste can be scaled was demonstrated.

The last half of the chapter was devoted to the sense of smell. After discussing smell receptors, the methodology of studying smell was described. A discussion of the various attempts to classify and interrelate odors and their stimuli followed.

6

FIFTEEN

Perceptual Learning and Change

◆§ *DEVELOPMENT AND ADAPTATION IN SPACE PERCEPTION*

E. J. Gibson (1963) defined perceptual learning as "any relatively permanent and consistent change in the perception of a stimulus array, following practice or experience with this array." This definition seems to emphasize two things—practice and the relative permanence of the result—and, therefore, is a statement about perceptual change as seen or dealt with from the learning psychologist's standpoint. Many phenomena one might deal with in perceptual change are immediately initiated by a new set of conditions (a new stimulus array) that is either a very natural change in conditions or a totally artificial set suddenly imposed. In all cases, if we are to look at the matter from the standpoint of perception, the question is what the organism is prepared to do immediately and what sort of changed "stimulus-response" relations begin to be developed consequent to the input change. This question was not always dealt with in the area of sensation and perception, since it was taken for granted by many that perceptual responses were rigidly related to input conditions (or were "stimulus bound"). While the lawfulness implied here still can be assumed as far as the relation between impingement energy and sense organ is concerned, it need not be assumed that the perceptual response is rigidly (simply) connected with this energy, for the central nervous system of the perceiver may utilize the input in various ways.

It will undoubtedly seem that in dealing with perceptual learning, we are part of the time showing what the perceptual response to new impinge-

ment conditions is in comparison to the old and part of the time demonstrating that the organism can change its perceptual response even to an old set of outside conditions. Be this as it may, the focal consideration is the fact of *perceptual change*, particularly in the fully developed organism.

Gibson stated that her definition of perceptual learning excludes "sensory adaptation" and if we were to rigidly follow her, we might say that perceptual learning would be less relevant than sensory adaptation in the present context. She also excludes "figural after-effects" but would probably include the effects of sensory deprivation.

A fundamental question in this chapter is whether or not the same principles are involved in the modification of perception in adulthood as were involved in the development of perceptual response in the first place.

While perceptual learning and other modification involves several sense modalities even when a single modality is primarily involved, it also involves the participation of the muscle system. This system manipulates the relation of the organism to the environmental conditions (energies) to which the organism must react. With this participation as inescapable, there must be a lawful relation between what muscle systems do and the interpretation given the environment through such senses as vision. This poses the problem of conducting visual perceptual experimentation in such ways as to answer various questions regarding the relation between muscle and visual activities. Or, to put it another way, it requires the recognition of the possibility that muscle activity is part of the actual visual performance. A pertinent question at this point, then, is whether muscle participation is involved in the same way in bringing about initial perceptual development and in the modification of perception later on.

Inversion of the retinal image

One of the earliest experimental investigations of perceptual modification and adaptability was that of Stratton (1897), who conducted an investigation in which the relationship between the image on the retina and the visual target were reversed. It is well known that, with a simple lens system such as the eye, the image of the target is inverted—that is, what is the top of some item in the external world is represented at the bottom in the image. We say the image is upside down. This causes many people to ask why we do not see things upside down, a natural kind of question to ask when it is not realized that the essential feature of image pattern and its relation to externality is *stability* and its *ordinal connection* with externality. By this is meant that the results of responding on the basis of a retinal image must always turn out the same. This property of stability can best be illustrated by our relation to the gravitational system. If sometimes when you stepped off the edge of a platform you fell downward, and other times you

just kept on walking out into space, and at still other times something else happened, you could not function at all. It is the same way with the visual image, its position on the retina, and its shape and size and its movements across the retina must always lead to the same successful motor reaction as a response. When the various internal parts of the image are considered, this stability of relation is spoken of as ordinal stability. The question is what happens when stability is disturbed. Were disturbance variable and ever changing, little or nothing could be learned by it. So, when a change is to be made for experimental purposes, it must generally be a stable kind of change.

Stratton had his subject wear a lens system on one eye that inverted the already upside down image. The other eye was kept blindfolded. Thus he provided for his subject a wholly *new* but stable set of relations between image and externality. His subject now "saw" objects in a new way. When he reached for something, he reached in the wrong direction. When he heard sounds, he heard them coming from the wrong direction. Wearing the lens greatly disrupted his auditory motor behavior as well as the visual. To accomplish the simplest acts involved a great deal of fumbling and grasping. Placing food in the mouth was difficult but only when he relied on his visual sense to guide him. With the experimental eye closed, he could rely on kinesthesis with no difficulty. As soon as vision and kinesthesis were both involved, there was conflict. The disorientation continued for three days before it abated, and at the end of eight days a new visuomotor coordination became fairly effective. But, upon removal of the lens, disorientation was again set up. It disappeared, however, more quickly than the disruption upon first wearing the lens.

More recently, the same general investigation was performed by Snyder and Pronko (1952) in which the lenses were worn for 30 days. One thing that came out in this investigation was the difference between the "natural" characteristic of perception and its characteristic under critical and analytical conditions.

For example, when, toward the latter part of the investigation, the subject was asked whether a given scene looked upside down to him, the mere asking of the question abruptly changed how things looked. What to him the instant before looked all right (right side up) now began to look upside down. He stated that when he recalled how the scene had looked before he wore the glasses, he had to answer that it now looked upside down. He had been unaware of it and had not given a thought to the question of right-side-upness or up-side-downness.

The requirement for normal effective perception seems to be harmonious interaction between the various modalities of response. If they are in harmony, the scene looks all right and is right side up; if they are not, various forms of perceptual anomaly and trouble set in.

The effect of prolonged wearing of size lenses

In recent years, a second kind of change in retinal image relation to externality was instituted as an experimental tool. At the Dartmouth Eye Institute manipulation was made with the use of size lenses (the optical properties of which were described in Chapter Seven). It was pointed out that an axis-90 meridional size lens worn in front of one eye distorts the appearance of certain environments in certain ways. Wearing size lenses therefore constitutes one set of conditions in which perception is altered. The most relevant question is whether, during prolonged wearing of the lens, initial distortions in the visual field slowly or finally disappear. That is, can the visual mechanism adapt to the new conditions and enable the wearer to see things as he did prior to wearing the lens? This question was studied by Burian (1943).

Wearing an axis-90 lens in front of one eye not only distorts the field but causes discomfort in general such as eyestrain and nervous tension. The ambient wearer has to make motor adjustments owing to the conflict between where things look to be and where he reaches for them or where he steps. He feels insecure, especially in precarious situations such as in traffic. The disruption in visual perception is not as complete as it was in the Stratton and the Snyder-Pronko experiments, but it is nevertheless real and crucial.

Burian used three subjects all of whom wore the size lens all through their waking hours for from eight to fourteen days. The original effects gradually wore off, although environments lacking the usual features of rectilinear perspective found in rooms with edges of doors, windows, tables, walls, floors, and ceilings still posed problems. Environments lacking such features are rolling hills and wooded spaces where brush, weeds, vines, and so on are oriented in random directions.

The longer the lens was worn, the less noticeable were the distortions in the visual field, and they finally disappeared and remained absent so long as the environment contained abundant features of linear perspective. The change in image size produced by the lens showed some reduction, after wearing the lens, but was not obliterated even when perception improved. Hence it was not considered likely that the disappearance of perceptual distortion was to be attributed solely to peripheral factors but rather included central factors, often spoken of as psychological.

When the lenses were removed from the subjects' eyes, there was considerable shift in the location of objects but in a direction opposite to the shift produced when the lenses were first worn. The effect lingered for from one to three days. With precise measuring instruments, some effect could be demonstrated for a week or ten days after lens removal.

LEARNING AND ADAPTATION IN FIGURE AND FORM PERCEPTION

Reafference and exafference

Holst and Mittelstadt (1950) concluded from their work on animals that the role of body movement in vision is of two kinds: (1) one involved when movements are self-produced (active movement) and (2) one when movements are produced by an outside agent (passive movement). The changes in sensory stimulation that stem from active movement were called *reafference* and those consequent upon passive movement were called *exafference*. For an animal to effectively orient itself in space, it must be able to distinguish between the two sorts of input and utilize them differently. This means that changes in the visual target that are associated with active movement are dealt with differently than when the same target changes occur in association with passive movement. This sounds plausible enough and most anyone would assent to the surface meaning of the statement. But there is more to the matter than appears on the surface. The focal question is whether the animal can learn equally well under conditions of exafference and reafference, or whether it would be possible to learn at all under exafference.

Experiments with prisms

A way to test the problem just posed is to require subjects to wear prisms befoe one eye while occluding the other. This changes the relation between externality and the spatial information provided by the retinal image. Such experiments were described in previous sections, but Held and his associates applied the principle somewhat more definitively by dealing not with the visual environment as a total but by dealing with perception of figure and form.

One sort of investigation conducted by Held was based on the fact that the effective location of visual targets can be altered by interposing a prism between them and the perceiver. If the perceiver is asked to point to or reach for the object seen, he will mispoint or misreach. Helmholtz many years ago asserted that, with practice, the perceiver under such conditions can learn to reach in more nearly the right direction or the right amount. Furthermore, when the original conditions are reinstated, the perceiver finds himself again in trouble. He misreaches in the direction opposite to his misreaching under the original conditions. The classical interpretation has been that the perceiver comes to recognize his error and, consequently, corrects for it. Held doubted this interpretation. He supposed that a single basic mechanism underlies both the *acquisition* of skill in the first place

and the *adaptation* to changes in the stimulus situations later on. He felt that simply an error-correcting mechanism could scarcely account for developing the skilled performance in the first place. The experiments of Held and his co-workers are numerous so we can describe only a few of them here.

Held and Schlank (1959) performed the following experiment. Using an apparatus consisting of a light box with upper and lower compartments, subjects marked the apparent location of a target contained in the upper compartment (Fig. 15.1). The image of the target was reflected to the eye

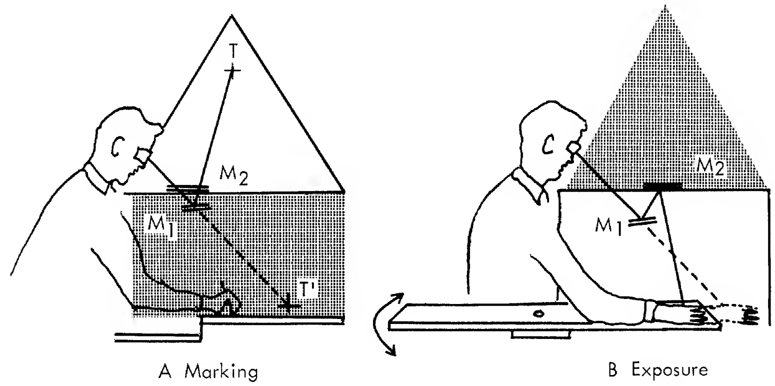


Fig. 15.1. Held and Schlank's experiment, using a prism to change the apparent location of position of visual target. (R. Held & M. Schlank. Adaptation to disarranged eye-hand coordination in the distance dimension. *Amer. J. Psychol.*, 1959, 72, 603–605, Fig. 1.)

by a fully reflecting mirror below the half-silvered mirror that formed the partition between the two compartments. The hand was in the lower compartment, and whether it or the target was visible depended upon which compartment was illuminated. A biting-board secured the subject's head in a fixed position. In the first part of the task, the subject saw not his hand but only the target. In the next part of the task, the subject saw his hand at an increased optical distance owing to the combined optical action of the two mirrors. This apparent increase in distance was about three inches at the level of the marking surface. Then, the arm and hand were moved while the subject watched. One form of movement was made through the subject's own efforts (active movement). In the other, the experimenter moved the swiveled cradle supporting the arm and hand (passive movement). The question then was how much, if any, adaptation (compensatory or corrective adjustment) would occur by virtue of either type of movement.

The compensatory shift following active arm movement was significant

in amount and in the right direction whereas the change with passive movement was essentially zero. Thus, the results of the investigation supported the Holst-Mittelstadt reafference hypothesis.

The question of what conditions are required to achieve full compensation for visual arrangement of the environment was considered by Held and Bossom (1961). They were also concerned with whether the same principle seemed to hold for compensation for errors ("adaptation") as have been shown to be involved in the development of perception in the first place. Riesen and Aarons (1959) found that gross bodily movements under natural conditions of exposure were needed for the development of perception in their experimental animals.

Held and Bossom seated their subjects in a revolving chair that could be rotated by leg movements. The position of the subject's head was fixed by a bite-board which rotated around the same axis as the subject's body. A drum 5 feet in diameter was mounted so as to be revolvable around the same axis as the subject with its midlevel at the subject's eye level. Targets located inside the drum were a luminous vertical 2-inch slit and a vertical line when room illumination was used. The view of the line was restricted so as not to include any information as to direction based on drum position or other visual cues. During target exposure, the subject wore goggles that eliminated all but 60° of the central field of each eye. Each eye viewed this field through a 20-diopter prism that caused an 11° lateral deviation of the field.

Two experimental conditions were used. Preactivity of self-produced movement was provided by having the subject, wearing the prisms, walk along a path lined with trees and an occasional building. Equivalent *passive* movement was provided by having the subject pushed along the same path in a wheelchair.

In Experiment 1, fifteen subjects were given two one-hour pretest activity trials of walking along the path. In one trial, they wore base-right prisms, in the other base-left prisms. At least one day separated the trials. As a result, these subjects compensated for a little more than 10 percent of the prism-induced errors when tested in the chair-drum setup. The subjects with passive motion manifested negative, nonsignificant amounts of shift.

In Experiment 2, fifteen subjects walked from 11 to 21 hours distributed over four days of pretest activity. Eight of the fifteen attained full compensation for the prism-produced distortions of the visual field. The other subjects did not reach full compensation by the end of the four days. Two subjects run with passive pretest exposure manifested no significant compensation even with the four-day exposure.

The investigators believed that the similarity of exposure times needed for *adaptation* (compensation) to rearrangement and for *development* of effective perception in the first place is to be interpreted as evidence for an identical mechanism involved in both.

Whereas in Held and Bossom's study full compensation for *rearrangement* of the visual environment such as produced by wearing prisms was tested, the question of the nature and consequences of *disarrangement* of the environment was entertained in the following one. The conditions that had been used in *re*arrangement involved the subject's exposure to transformations in the relation between motor output and sensory feedback in an isomorphic, continuous, and time-independent manner. This is to say that an essentially lawful connection was maintained between the movements made and their effective consequences. In *dis*arrangement, a fundamentally different set of conditions was used in which no fixed and stable connection between body movements and their consequences existed. This can be illustrated in other situations. For example, when the individual is in free flight (weightlessness), he may flail his arms, make stepping movements, and do all sorts of things and find that there is an unpredictable relation between his movements and their consequences. Such conditions are not attainable for most experimenters, however, but there are laboratory setups in which discrepancies between perceived object positions and where the objects can be successfully reached for are varied during pretest exposure. These conditions are achieved by using rotary prisms. A rotary prism is an optical system of two wedge prisms whose mutual relations can be suddenly changed at any time or amount or changed slowly in a sequential pattern decided by the experimenter. For example, when two equal wedge prisms are placed with their bases opposite (Fig. 15.2), their combined refractive effect is zero. When their bases are together, their effects add and are maximum. So, if by some means one prism is rotated in relation to the other, which is held in a fixed position, the amount of perceived shift in the position of target is varied. Using such an optical arrangement, there is no fixed relation between the reafferent effect of muscle activity and seen position of the target. The authors suspected that after some exposure to such conditions, the ability of the subject to use reafference might become impaired, which would be evidenced in increased ambiguity in response to relevant sensory signals.

Held and Freedman (1963) used *dis*arrangement. They used a prism of variable power whose maximum was 40 diopters. Otherwise, their general setup was the same as for testing simple *re*arrangement. One subject was tested in two different 64-minute sessions in which both right-and-left and up-and-down displacement of target elements were produced. The subject was instructed to move his forearm and hand back and forth while he looked at it through the prism. The subsequent test-task was the marking of the position of a small cross. After the introduction of the rotary prism the markings increased in their scatter. Their dispersion was greatest along the dimension of optical displacement produced by the prism. The markings did not show significant changes in dispersion at right angles to the prism displacements or in the mean positions of the marks as a group.

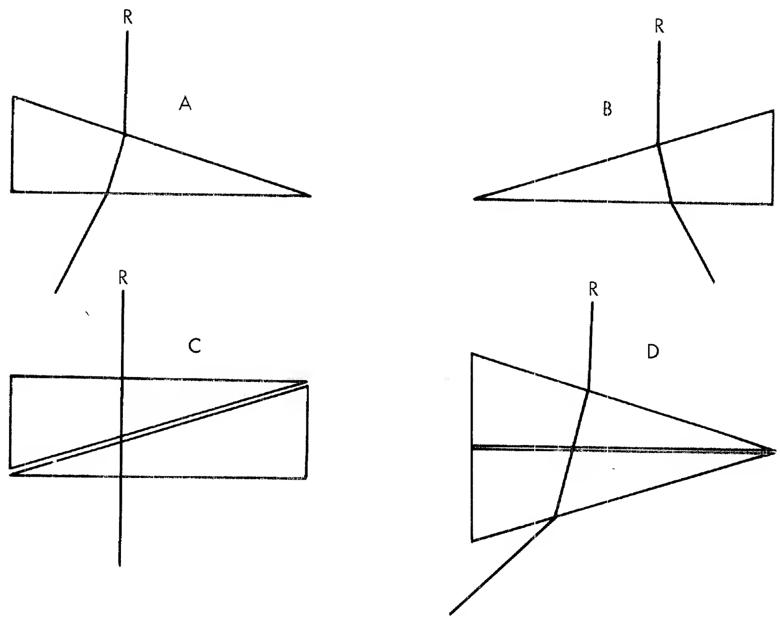


Fig. 15.2. The principle of rotary prisms.

Even though the rotation of the prisms went through fixed cycles during testing, the variation in the positions of the marks showed no covariation with the cycles, indicating that no learning of the cycles was taking place.

The reduction in the accuracy of the markings indicated that the eye-hand control system was being degraded in the dimension specific to the time-varying factor of the prism strength. Eight subjects were later tested for the difference between the effects of passive and active movement conditions. It was found that the same degrading of test behavior did not result from the passive movement conditions. This seemed to show that it is *active* movement under *dis*arrangement conditions that brings about the degradation. Passive movement is neither an aid to compensatory achievement in rearrangement nor a means of degradation of eye-hand control in conditions of disarrangement.

Two types of adaptation to an optically rotated field

The experiments on adaptation to optically rearranged visual fields far from tell the whole story. Accordingly, certain other experiments were made. It seemed from the well-known results of first Wundt (1898) and then J. J. Gibson (1933), that viewing certain targets was a process that in itself produced changes in the viewer. Gibson reported several experiments of this sort. The effect of parallel lines looking curved through wedge prisms

tended to diminish, if not totally disappear, upon extended viewing. When the prisms were removed, the straight lines of the target again appeared curved but in the opposite direction. The same effect was noticed when a subject viewed a target with a line tilted slightly off the vertical. Soon it might tend to look vertical, but then if a vertical line were presented it looked tilted but in the opposite direction. This type of experiment was the forerunner of the study of figural after-effects by Köhler and Wallach (1944). Since such effects differ from those mentioned in the previous section, there seem to be two types of adaptation.

Mikaelian and Held (1964) studied the two types by studying the after-effects of viewing two different environments through prisms that rotated the retinal images 20°. In Experiment 1, the environment was a long hallway viewed as a pretest situation following active movement of the subject while wearing the prisms. Some subjects achieved full and exact compensation for the effects as tested by adjusting a target line to the vertical and by making equivalent shifts in the egocentric localization of two target points. Subjects who were given passive movement over the same path in a wheelchair achieved small but significant corrective shifts in the line but failed to make shifts in the point settings.

In Experiment 2, the subjects were placed in a figured environment in which grid-like patterns of straight lines were involved. Active exposure to this environment while wearing prisms resulted in the same shifts as for the first environment. There were no shifts produced, however, for passive movement in the environment.

The results confirmed the criteria that the workers had outlined in the beginning for distinguishing aftereffects produced as a result of wearing prisms in a normal environment and under Gibson's conditions. The after-effects produced by prisms were of the following sort: (1) they reached a magnitude equivalent to the rotation of the visual field produced by wearing the prisms, (2) they required self-produced movement (active movement) of the wearer of the prisms, and (3) they showed up not only as an apparent tilting of the line target but also in the egocentric location of single tested points in the field remote from the line. Gibson's after-effect was suggested as not exceeding 2° or 3° tilt and not requiring any active movement of the observer and occurring without accompanying shifts in the subjective location of points in the visual field.

Held and Mikaelian (1964) went still further. They faced the suggestion that passive movement (being moved by wheelchair) failed to produce results typical of active movement situations because in the passive movement "need" was lacking. They examined results produced when, instead of being moved by someone else pushing the wheelchair, the subjects propelled the chair themselves. The investigation showed that the subjects who propelled themselves by wheelchair manifested little, if any, compensation for the prism effect despite their *need* to deal with directional errors and to take advantage of the information.

The factor of felt position of body part in reaching response

Several investigators have believed that adaptation to target rearrangement accrues from a change in the felt position of body parts relative to each other. This view is based upon the fact that the changed direction of reaching for visual targets, after seeing the optically displaced hand, shows up when the subject points to nonvisible targets (sound sources). This generalized adaptation including nonvisible targets is said to result from a proprioceptive change underlying the felt position of the reaching arm.

While this may seem plausible for certain limited sets of findings, Efstathiou, Bauer, Greene, and Held (1967) believe they have shown that such an interpretation is not in line with the following experiments they conducted. Some years ago, it was shown (Scholl, 1926) that the adaptation in reaching for a visible target by one hand is also evident in reaching for a nonvisible target, for example, reaching for the other, unseen hand. The Efstathiou experiment sought to test these two forms of adaptation under fully comparable conditions.

Reaching for a visible target was checked by having the subject mark on a sheet of paper, while not seeing his hand, the perceived location of the virtual images of four points seen with both eyes through a fully reflecting mirror (Fig. 15.3). To the viewer the points appeared to lie on the

Fig. 15.3. Apparatus used by Efstathiou *et al.* to test certain forms of perceptual adaptation. (A) = the virtual images of four target points seen binocularly in a fully reflecting mirror; targets appear to lie on the table surface. (B) = index finger placed successively on each of four pins protruding from the underside of the table, corresponding to positions of the visible points. (C) = four removable pins protruding above table surface. (A. Efstathiou, J. Bauer, M. Greene, & R. Held. Altered reaching following adaptation to optical displacement of the hand. *J. exp. Psychol.*, 1967, **73**, 113–120, Fig. 1.)

table surface about perpendicular to his line of sight (frontal plane). The viewer's visual field was restricted to the target area by lenseless goggles.

Reaching for the nonvisible hand was tested by having the viewer mark on the same surface, with eyes occluded (blindfolded), the perceived positions of the index finger of the hand. This finger was placed successively on each of the positions on pins protruding from the underside of the table where the contralateral finger touched one pin at a time. Through all the experiment, the viewer's head was held stationary by a bite-board.

In all, they performed three different experiments in this investigation. The amount of the shift varied with the type of target. The results suggest two independent forms of reaching: one based on equating arm movements and possible head orientations toward a target and the other based on the felt position of the arm. The first is changed by adaptation. The second is unaltered and tends to limit the shifts resulting from the first.

Visual adaptation when no part of the body is seen

McLaughlin, Rifkin, and Webster (1966) showed that when an observer looks at a visual target through prisms, adaptive changes occur even when he sees no part of his own body as a visual reference. They stated that these changes stem from "a change in judgment of the direction of gaze," an oculomotor change arising from two secondary prismatic effects: the asymmetry of the visual scene and the apparent rotation about the vertical axis of a plane surface such as a wall in front of the observer. They stated that the first effect is responsible for a part of the change and the second is responsible for the remaining and major part. The first factor is not aided by eye-movement activity.

The procedure used a target that was a luminous 3-centimeter line, 0.3 centimeter in width viewed from a point 33 centimeters away. The observer's head was held fixed by a biting-board with dental impression. Without prisms the target appeared straight ahead. Just below the target was a horizontal track carrying a movable pointer. The track and target were mounted on a vertical plywood panel. Only the target was visible when the room was unilluminated. With the usual room illumination, the observer could also see the pointer and his right hand. Other features of the visual field were occluded from view. A prism was then placed in front of each eye, producing an angular deviation of about 11° to the right. The observer made his own settings with his right hand.

In the unilluminated room the observer was asked to set the pointer straight ahead (setting 1). Then, when the target was illuminated, he was again asked to set the pointer straight ahead (setting 2). For the next setting, the pointer was set so that its tip was directly beneah the target (setting 3). Following this, a 5-second adaptive exposure was provided. Then, settings 2 and 3 and the adaptive exposures were repeated fifteen times, omitting the final adaptive exposure.

In a single experimental period, four different adaptive conditions were used. In A, the visual target was merely viewed in the unilluminated room. In B, the hand was removed from the pointer, the room was illuminated, and the pointer was set directly beneath the line. Under this condition, the pointer and the panel were visible and the tip of the pointer was fixated. In C, the conditions of B prevailed but the pointer was moved back and forth while its tip was fixated. In D, the observer kept his hand on the pointer, and he could see his hand, pointer, and the target. In this condition, he was told to set the pointer directly beneath the target. Before each of the adaptive periods, 3 to 5 minutes of eye-hand activity with the prisms omitted were given.

The results were summarized essentially as follows.

1. When a small target viewed through prisms is the only thing visible, a small adaptive oculomotor change occurs. That is, the perceived position of the target is not deviated as much as the value of the prism would indicate. There is a proprioceptive compensation also, which the experimenters attributed to a "cognitive effect" stemming from previous knowledge of the "true" position of the target. The oculomotor effect (compensation) is attributed to the asymmetry of the visual field seen through the prisms.

2. When an illuminated surround is used, there is large adaptive oculomotor effect and a small proprioceptive change in the opposite (non-adaptive direction).

3. The oculomotor adaptive effect is not increased by oculomotor activity.

4. It is suggested that investigators who found reafference (muscle activity) necessary for adapting to visual displacement by prisms were dealing mostly with proprioceptive adaptive changes. On the other hand, those who found adaptation resulting without reafference were dealing mostly with oculomotor adaption.

Immediate perceptual "correction"

Rock, Goldberg, and Mack (1966) showed that when a target is viewed through prisms an immediate "correction" of the visual displacement occurs. Objects appear to lie closer to the "true" direction than the direction that would be expected from the optics of the prisms.

In their experiment, a luminous spot was the target in an unilluminated room. Its position could be adjusted vertically or horizontally by the observer. The observer was brought blindfolded into the room and his head position was fixed by a biting-board. After removal of the blindfold, he was asked to adjust the spot so that it looked straight ahead. Then prisms were placed in front of his eyes and he was again asked to adjust the spot so that it appeared to be straight ahead. Twenty-diopter prisms were

used. From these, it was expected that the new location would be about 11° from the position determined with naked eyes. Following this, the room lights were turned on and the observer was again asked to position the spot. The difference between the preceding position and the one now indicated was taken as the measure of the correction effect.

Eradication of confusion in perception

Initially confusable items of sensory input may become distinguishable with practice. This shift is another form of perceptual learning or change. To account for it two opposing views have given rise to specific investigations. Gibson and Gibson (1955) called them the *differentiation view* and the *enrichment view*. The former says that practice functions to reduce generalization among the items of input, to increase precision of discrimination of the variables present, and to detect relevant variables or distinctive aspects not previously detected. This view requires a new concept of stimulation since it holds that effective stimuli for perception are changed by the learning process. What is implied here is reminiscent of the present author's distinction between impingement and stimulus, discussed earlier (page 14).

The enrichment view quite differently emphasizes addition to perceptual features by the process of association. This seems to be a new form of Titchener's context theory and would suppose that the newly emerging perception would become more distinctive by the addition of meaningful associations. But putting matters this way does not seem to display much explanatory power.

The study of factors for or against discriminability does not always include the demonstration of learning within the study itself. Learning sometimes becomes a matter to explain the results of the study. Liberman and his colleagues (1961) measured the discriminability of the acoustic differences within and between phoneme boundaries and compared the results with acoustic differences in inputs not perceived as speech. The subjects discriminated better across phoneme boundaries than in the middle of a phoneme class. The results with the control inputs disclosed no superiority in discriminability in the region corresponding to the phoneme boundary. The conclusion was that the increase in discrimination at the phoneme boundary is the result of learning, which is to say it is an "acquired distinctiveness" from long practice in attaching phoneme lables. Other experimenters have obtained similar results.

Pick (1965) wanted to determine whether, in discriminating standard from comparison figures, the subject comes to identify the absolute features of the standard figures or the features of variation distinguishing it from the comparison figures. The first is called prototype learning, the second transformation learning. Her study included both visual and tactual presentations. She compared the subject's transfer of the original discrimination to

one of two tasks involving a response either to the absolute features of the original standard or to the dimensions of variation among the presentations. When standard and comparison were presented simultaneously, transformation learning seemed to occur in both visual and tactual tasks. With successive presentations (studied only in touch), the difference between the two required responses disappeared. It was expected that successive presentations would be more conducive to learning the absolute features of the stimulus presentations.

E. J. Gibson and colleagues (1962) believed that a skilled reader would visually discriminate letter-groups constructed in accordance with the rules of spelling-to-sound correspondence better than groups only partially of this sort or not at all. They presented appropriate letter-groups tachistoscopically. In a try-out group of 121 subjects, greater discrimination resulted for the pronounceable letter combinations than for the unpronounceable ones. In a later experiment, their subjects reproduced more accurately letter combinations that could be pronounced than the other letter combinations. In a third experiment, essentially the same results were obtained with tachistoscopic presentations whose discriminations were demonstrated by matching their perceptions with items in a multiple-choice list.

Learning in the perception of slant

Freeman (1966b) studied the learning of visual slant. He found that the effectiveness of cues to slant may be modified by differential reinforcement or by instructions. In the experimental conditions he used there were probably only two possible cues to slant, the major-minor axis ratio of the retinal image and perspective. All other binocular cues and extreme monocular cues were eliminated. In spite of this, large errors of judgment occurred in slant-matching as a function of the physical size of the plane rectangles used as targets. Freeman attributed preexperimental error to the greater perspective weight (or cue) to the larger targets and to the relevance of the perspective cue required of the observers. He gave reinforcement when the observer's responses corresponded with the physical slant of the targets. In as many as half the trials positive reinforcement was given for a "greater slant" response in which the perspective cue of the more slanted target was less than that of the less slanted target. In other trials, the opposite situation response was reinforced. The major-minor axis ratio of the retinal image tallied nearly perfectly with the experimental reinforcement. The results supported the prediction of his cue-relevance theory.

Split-brain investigations

"Split-brain" investigations consist in determining an animal's sensory behavior following the transection of the neural connections between the two cerebral hemispheres. This sort of operation might be expected to in-

capacitate the subject since it produces a radical change in the functional anatomy of the nervous system. It separates (splits) the two gross structures that ordinarily work together to achieve a unitary (or consistent) behavioral result. Such radical interference with the nervous system would be expected to have crucial effects on perception, altering and reducing what the organism would be able to do. The question then is to determine what postoperational perceptual response is like and what sorts of adaptation and improvement can be brought about by practice.

The actual behavioral results of split-brain operations have not turned out to be as anticipated but they have been most instructive. The first finding was that an animal with a split brain can function quite effectively. Some stimulation reaches both hemispheres when no control is put upon sensory input, and thus ordinary circumstances do not test what a single hemisphere can do. Experimentation consisted in delivering sensory input to only a single hemisphere. It was found that, in many respects, successful response could be elicited.

It was then found that response learned by one cerebral hemisphere was not transferred to the other one. For example, visual targets whose images were so placed on the retina as to activate areas feeding into only one hemisphere were used as the original stimulus material. When a discriminatory response was learned under such conditions, the animal was tested by having the target imaged on retinal areas feeding into the other hemisphere. The response in the second case showed no advantage of the previous learning in the first hemisphere. The correct response had to be learned, just as had the response using the first hemisphere.

Experiments with other modalities such as touch were conducted and yielded the same sort of result. Surface texture was used as the differential feature; the animal had to learn to choose between two textures on the two pedals that could be operated to obtain food. Whereas an intact animal could perform with the second paw what had been learned by using the first paw, cutting the corpus callosum—separating the two hemispheres—made this impossible. Such experiments were performed on cats and monkeys, and it was concluded that the two hemispheres are required in these species for integrating the two halves of the visual field and for integrating inputs from the two opposite limbs.

Split-brain operations were finally performed on humans. This was first contemplated for severe epileptic patients. The evidence from work on animals that such an operation might very likely do away with the intense epileptic seizures made the risk morally justifiable. The expectation was realized and, in ordinary situations, little if any degradation in behavior could be noticed.

As already pointed out, in everyday situations no control is exercised upon which hemisphere receives a given kind of information. Both hemispheres, even in a split-brain patient, generally receive information in the

usual ambient situations. It was necessary, therefore, to subject split-brain patients to controlled experimental situations to test behavior stemming from the action of a single hemisphere. Gazzaniga, Bogen and Sperry (1963, 1965) were the first to experiment with split-brain subjects after operations to cure epileptic seizures.

The first finding obtained from the very first case was that the operation disconnecting the two hemispheres had cured the seizures. The second finding was that the patients were left with two "minds." The meaning of this statement will shortly become apparent. Another finding was that the left hemisphere provided the subject with the ability to speak. The other hemisphere provided all the behavior of the left hemisphere except speech.

In one experiment, the subject was seated in front of two screens transilluminated from the rear and separated from each other by 4 inches. Midway between the two was a fixation point. The first test in the series pertained to pattern discrimination in which a pattern was to be chosen from five others appearing on cards on the table in front of the subject. The item to be chosen from the cards was briefly presented on one or the other or both of the screens. Generally, a new set of cards was used for each trial. One of the cards contained the item that was flashed, one was blank, and the other three contained incorrect items. The materials used were geometrical forms, words, and short phrases. In some trials the subject was to make a verbal response, in others only a manual one. The task, in each trial, was to pick out the item most like or identical to the item presented.

The right hand responded with nearly perfect accuracy to all right screen presentations and only at a chance level to those on the left. The performance of the left hand to left screen presentations was two and a half times better than chance. The left hand seldom made responses to right-field presentations and those that were made were only at a chance level of correctness. With left-screen presentations, the subject when questioned denied having seen anything and often even seemed puzzled that the questions had been asked. This was in spite of having made the correct manual retrieval response.

For the trials in which the presentations were made on both screens, each hand made its correct response, just as when the presentation was on its own screen alone. No conflict of any sort appeared. Verbal recognition continued to be specific to right-screen stimuli.

A different sort of visual presentation apparatus was used for another set of tests so constructed that separate discrimination tests could be provided for each hand. Each half-field was composed of two small screens upon which small figures could be presented. Four normals and four split-brain subjects were compared in the relative amounts of time required to make discriminations. In normals, the hand took about 40 percent longer to discriminate its own half-field when simultaneous presentations of both half-fields were given. The split-brain subjects showed no difference in

response latency whether only one or both half-fields were presented. This seemed to indicate that the split-brain subjects were not involved in a kind of interference characteristic of the normals. One patient, for example, was tested in his ability to draw with the right and left hands. The patient was righthanded and never had had occasion to draw with his left before the operation. To get the left hand to perform in the experiment, the test was started with the right hand and with verbal instructions. After some familiarity with the procedure, a shift was made to the left hand by a demonstration from the experimenter and instructions to "do this." The use of the two hands was alternated with three minutes allowed for each drawing. A kind of anomalous activity of the left hand was observed a number of times. The hand would tighten and go out of control toward the end of the three-minute effort. It would swing upward to a position above the left shoulder.

In a later experiment, the object to be drawn was a Necker cube. The right hand was given the task of drawing it, after a demonstration by the experimenter of drawing two overlapping squares and connecting their corners. This task seemed to be impossible for the right hand. Immediately after this failure, the left hand drew the complete cube without using the demonstrated technique. The right hand could construct only simple figures and only after considerable practice.

When the task was constructing standard patterns with blocks with the free use of both hands, the patient was usually unable to achieve the goal, largely because the right hand would try to assist the left, and in so doing would undo the effective accomplishments of the left hand.

The behaviors dependent upon other sense modalities were also tested. It was found that areas on the left side of the body, not cross-localized by the right hand, were unable of evoking a correct verbal response regarding which of two presentations felt hotter or colder. But, if a warm or cool glass of water were provided and the subject was asked to select the proper glass of water from two others, he was able to do very well. If the task was made intermanual, the performance dropped to the chance level. The areas on the head or face taken to be bilaterally represented in the nervous system were quite capable in thermal discrimination expressed either verbally or manually. The same mapping of bilateral and unilateral areas found to function for touch and temperature seemed to function for pain-producing stimuli.

To test the ability to perceive position (the kinesthetic sense) the joints at the wrist, elbow, shoulder, knee, and ankle were placed in specific positions and the blindfolded patient was asked to state the position in which the distal part of the limb was pointing. For the right hand and foot, there was no difficulty manifested, but the patient was completely unable to describe the positions displayed by the fingers, wrist, and toes on the left side of the body. The sense of position of the left shoulder was retained but for the elbow it was variable.

PERCEPTION IN SENSORY DEPRIVATION

Sensory deprivation is of two sorts, that which occurs from birth and that which is induced later on. In animals, the former can be brought about experimentally, whereas in humans only accidental deprivation is thinkable. We have already described the work of Senden, who accumulated the records on a number of congenital cataract cases.

It turns out, however, that the term sensory deprivation as applied to humans generally refers to experimental deprivation for short periods of time in the adult. Such deprivation is not the occlusion of one sense modality but rather the attempt to preclude stimulation of as much sensory input to all senses as possible. Inasmuch as reports can be obtained from humans regarding their introspective behavior while in deprivation, this period as well as the postdeprivation period is of interest. The deprivation period is not a study of the effects of stimulation but of what happens when stimulation is minimized or withdrawn.

The hypothesis that an organism requires not only stimulation (that is, sensory impingement) but a quite varied input has been put forth in recent years and has been put to test by a number of investigators. This hypothesis has included the idea that perceptual disorganization is the expected consequence of lack of stimulation. One might say then that this disorganization would be expected to include systematized hallucinations on the one hand and curious or unusual interpretations of sensory inputs on the other. It is on account of the connection between the results of sensory deprivation and the usual results of sensory stimulation that sensory deprivation is brought up at this point.

Actually, the boundaries between ordinary perception, illusion, and hallucination are less distinct than is ordinarily supposed. "Isolation" and "sensory deprivation" are two of the most frequently used terms to label the various conditions referred to. Isolation may be classified as (1) *confinement* to a restricted space or time; (2) *separation* from specific persons, locales, or things to which the individual has become attached or dependent; (3) *extreme reduction of stimulation* by a process of removal from the total environment; and (4) *regularization* (making uniform) of stimulation to the point at which it is no longer perceived. From the perceiver's standpoint, this latter condition is spoken of as monotony.

We have as informational resources the autobiographical accounts of those who have undergone isolation, and we also have the findings from laboratory experiments on sensory deprivation. Of the individuals who have undergone isolation, there are three general groups: those who have done so for religious or "spiritual" reasons, those who have been forced to under political or military duress, and those who have done so in the course of carrying out some work objective. The recounted experiences of the mystics are quite numerous and we shall not take space for examples.

Isolation incidental to a work task is exemplified in an experience of Admiral Richard Byrd, who was buried in a small hut in the Antarctic for six months, originally with the intention of testing peace, quiet, and solitude in order to find out "how good they really are." Snowed in during the polar night, this life, with its confinement, with its visual and acoustic monotony, soon shifted to a veritable nightmare. Along with the sensory deprivation, there was bone-chilling cold, the hazard of carbon monoxide poisoning from the oil heating stove, and even the possibility of collapse of the ice structure in which he was entombed. Apathy and inertia came over him till he was all but unable to tend to the matters of eating, drinking, and keeping warm. He mainly lay abed, inert, hallucinating and experiencing all kinds of bizarre notions. This inertia verged into the feeling of "oneness with the universe," actually a very natural consequence of routine minimization of response to externality.

The sorts of results most appropriate to discussion here have been obtained under experimental conditions (Bexton, 1953; Bexton, Heron, and Scott, 1954; Doane, 1955; Doane, Mahatoo, Heron, and Scott, 1959; Hebb, Heath, and Stuart, 1954; Heron, Doane, and Scott, 1956; Scott, 1954; Scott, Bexton, Heron, and Doane, 1959). The conditions used in the original studies at McGill (Bexton *et al.*, Heron *et al.*, *Scott et al.*) were as follows. Male college students were hired to lie in comfortable beds as long as they could (about 3 or 4 days). The beds were in lighted, semisoundproof cubicles 8 by 4 by 6 feet that had been fitted with a window for observation from outside the room. The subjects wore translucent goggles that admitted illumination but precluded form vision. Except when eating or going to the toilet, they wore cotton gloves and had their arms in cardboard cylinders from the elbow to beyond the fingertips. Auditory perception was greatly limited by the continuous hum of the earphones in their foam-rubber pillows, which provided the only intercommunication between subject and experimenter. An experimenter was always present outside the cubicle, day and night. While the subjects were informed that if they needed anything they should call for it, they were not informed of the time of day or night.

The subjects usually spent the early part of their isolation by sleeping. As time wore on, they slept less and seemed eager for stimulation. Their overt behavior consisted in talking to themselves, singing to themselves, and tapping the cardboard cylinders together or using them to explore the interior of the cubicle. They became restless and their movements became random.

Considerable emotional lability was manifested. During their stay they were given certain tests, about which they remarked more freely than when tested outside the cubicle. Most subjects reported elation during the early part of isolation, but this changed to irritability, which increased toward the end.

When the subjects terminated their isolation and came out and had their goggles and gloves removed, they seemed dazed. They mentioned some disturbance in visual perception usually for a minute or two. They had difficulty in focusing; things looked two-dimensional; color seemed enhanced. Some reported confusion; some, mild nausea; some, headaches. In some cases, the symptoms continued for 24 hours.

The phenomena reported as pertaining to the period within the cubicle included inability to concentrate on any topic, inability to conduct organized thinking, lapses into uncontrolled daydreaming, and the emergence of "blank periods." From tests administered in some of the studies, such functions as number-series completion, word-making, and digit-symbol substitution were impaired. Tests on figural after-effects, size constancy, tactual form perception, and spatial orientation showed that some subjects were not affected, but the overall results could be interpreted as evidencing the deterioration of cognition and motivation. A major consequence of isolation was the emergence of hallucinations. Some referred to "having dreams while awake." The hallucinations involved audition as well as vision. Feelings of "otherness" and "bodily strangeness" were also common.

The results including both the tests and the hallucinations led the investigators to conclude that merely limiting the environment as they had gave quite direct evidence of a form of dependence upon the environment not previously realized. Subsequent studies in other laboratories differed somewhat in certain findings, but the conditions of experimentation were also different.

SUMMARY

This chapter has been divided into three sections, the first of which pertained to development and adaptation in space perception. One of the major techniques in the study of the phenomena involved has been the use of prisms to shift the apparent position of seen objects. With some practice, the discrepancy between where the item looks to be and where it can be reached by the hand disappears.

The second section also pertained to learning and adaptation, but concerned itself with the matters of *reafference* and *exafference*. Reafference is the stimulation obtained by the use of active muscular participation in the perceiver's dealing with items whose anomalously perceived position has to be adjusted to. Among the experiments described was one on the wearing of size-lenses, which definitely distort the visual field. Such an investigation was aimed at elucidating the underlying nature and basis for a visual anomaly called *aniseikonia*, a kind of distorted space perception. Another feature of learning discussed was learning in the perception of slant.

The chapter also dealt with experiments conducted on animals and men whose two cerebral hemispheres had been disconnected by surgery. In humans, it was found that this operation obliterated the severe convulsions of epilepsy. But since the higher animals and man are bilaterally structured, the question arose as to whether what was learned by use of one cerebral hemisphere would be reflected in the activity directed by the other hemisphere. The various experiments on man are among the most interesting and important in all experimental psychology.

The chapter ended with a presentation of the major findings regarding sensory deprivation.

SIXTEEN

Studies in Social Perception

Social psychologists are interested in what they call social perception. The problems in this area are very different from the more traditional problems of perception. Whereas the problem of relating, identifying, or distinguishing between perceptions was traditionally so involved as to maintain the study of perception as something largely "stimulus bound," social psychologists have taken up perception as something crucially determined by the specific character or state of the individual perceiver. It is not that character and individual state were totally unrecognized or ignored by psychologists studying perception in the usual manner; it is simply that social psychologists have seemed to feel that the "contribution of the organism"—more particularly, the highly specific and labial factors influenced by the social environment—have not received enough attention or have not been studied in quite the right way. Interest in social perception came as a burst and, at present, does not occupy as relatively prominent a place in the whole horizon of social psychology as it did for a time. The present chapter attempts to provide a sampling of the kinds of studies in perception made by social psychologists.

If in insisting that perception is social one is only emphasizing that it is characterized by flexibility, then he is merely describing one species of perception of properties already reviewed in the preceding chapters. However, the connection between social processes and perception must be made explicit and understandable. At present there seem to be three aspects to what is called social influence. First is the influence brought about rather directly by other people. It may be operative through the presence, examples, wishes, or prestige of other people even though these other people are not present. These influences are not always detectable for what they are

and it requires considerable ingenuity to ferret them out and make sure they actually are involved in specific cases. Possibly in this same category, or at least in one analogous to it, are the perceptual responses that are what they are by reason of specific personal need. They represent the subject's value system in ways not so clearly assignable to social influences as to his own personality.

The second aspect of social influence is one in which socially meaningful and socially originated properties are responded to. As an example, there is the immediate response that is guided by a social concept or ideal. The perceptual properties of situations are socially describable and evolve only in a social context. This differs from the first sort of social perception in that it may pertain to a physical property of a physical object, such as size or shape. Superficially there may be nothing present at all social. Only when the investigator suspects a social influence and designs an experiment appropriate for checking on the matter does the social aspect of the perception emerge. For example, if it is found that one class of people sees certain objects as possessing one physical value and some other class of persons perceives it differently, then a social influence may possibly be discovered by making several more steps in the investigation.

A third aspect is the phenomenon of individual differences. Some such differences in organisms are basically anatomical and are not acquired by reason of a social context, but others evolve out of the interaction between organisms. Some human perception is what it is because of this sort of interaction. When individual differences are manifested in human behavior and are not assignable to structural causes, the problem arises of whether and to what extent the differences are assignable to social interaction.

It is only proper that when the flexibility of perceptual response in relation to the environment is to become the focus of experimental attention the requisites for appropriate experimentation are followed. This caution might be omitted were it not so obvious that in a number of cases it has not been observed. It is quite proper to define perception or to bound it somehow so as to make it distinguishable from topics and processes with which it might be easily confused or intermingled.

We have, either explicitly or by implication and illustration, defined and delineated perception in the preceding chapters. The definition implies certain sorts of operations in experimentation. Because perception is a kind of behavior that is immediately linked with specifiable environmental conditions, it must be studied in ways that do not contradict the definition. Discovering unexpected facts that upset the definition is a different matter. But one must at least start out by attempting to adhere to what has been formulated.

One of the first departures is to design an experiment in which there is only a very loose connection between a given set of external conditions and the response. For example, when a subject is allowed to have all the

time he wishes to make a response once a presentation has been made, he can ruminate and consider a number of alternatives (guesses or what not) or he can go through a reasoning process to arrive at a response. Such experiments are appropriate for certain purposes but not for analyzing perception—unless perhaps the experimenter gets his definition of perception from the dictionary where perception is defined as knowledge, intuition, outlook, and so forth. Some definitions there do not even require that there be a stimulus.

CLASSES OF ASSUMPTIONS IN SOCIAL PERCEPTION

Allport (1955) lists six propositions found in the study of social perception, particularly as pertaining to the directive-state theory. They are: (1) that bodily need determines, within limits, what a subject will perceive; (2) that reward and punishment are also factors in determining what a subject will perceive and that they greatly influence thresholds at which items will be recognized; (3) that values represented in the personality of the perceiver tend to determine thresholds of recognition; (4) that the size perceptions evoked by stimuli are in line with the social value connotations involved; (5) that the personality features of the perceiver predispose him to perceive in a manner consistent with such features; and (6) that overt recognition reactions to personally disturbing stimuli have a longer latency than do reactions to neutral material, that this material tends to be misperceived in radical ways, and that it evokes autonomic reactions at thresholds below overt recognition thresholds.

It is not immediately obvious that these six categories are mutually exclusive. Some of them tend to sound as though they are simply different ways of saying the same thing. We shall try, not to clarify them at this point, but to follow the discussion of social perception as formulated by the workers in the field.

Bruner and Postman (Bruner, 1951) put the determinants of perception into two distinct categories: the structural and the behavioral or motivational. With reference to interest in these categories they divide the investigators past and present into "formalists" and "functionalists." The structural factors include the stimulus, the effects of the stimulus energy on sense organs, the afferent neural pathways, and the cortical projection areas of the sense modalities. The bodily factors are looked upon as the innate, given, and relatively fixed determinants; they are, for the most part, the relatively unchangeable endowment of the perceiver. The behavioral determinants, in contrast, involve the "higher level" processes; they have to do with the functional relation of the parts of the nervous system already mentioned, with the associational areas of the central nervous system. They perform a directive role in dealing with new sensory material. It is the na-

ture of this assumed central directive process and its influence upon perception and judgment that many social psychologists have turned to studying.

Bodily needs

The following are a few representative studies made by social psychologists in which factors having to do with personality and the interplay of social influences tend to modify perception of geometrical targets, or targets seen as words. The first study to be described was conducted by Levine, Chein, and Murphy (1942). They used as their target material eighty white cards with simple pictures seen through a ground-glass screen. The ground glass served to blur the pictures so as to make them very vague indeed. Forty of the cards contained black and gray pictures (achromatic series) and the other forty contained colored pictures (chromatic series). The cards included fifteen "meaningless" drawings, fifteen ambiguous drawings of food articles, and ten drawings of miscellaneous household articles. All the drawings, when viewed behind the screen, were ambiguous but could be seen as food articles by the hungry.

During each session, twenty achromatic and twenty chromatic cards were presented in random order. Two sessions taken together were called a trial, since the second session used the cards not used in the first session. The same cards, of course, were presented to both experimental and control groups. For the control group, some sessions were 45 minutes after eating, some 1 hour, some 1 1/2 hours, some 2 hours, and some 2 1/2 hours. The experimental group, however, was deprived of food for 1, 3, 6, and 9 hours.

The investigators found that autistic processes were definitely manifested under conditions of food deprivation in the experimental group. The subjects deprived for 3 hours showed more food responses than the 1 1/2-hour subjects, and the 6-hour subjects showed more responses than the 3-hour subjects for the achromatic, but not for the chromatic, cards. For the chromatic cards, the number of food responses at 6 hours decreased from the number at 3 hours. For both kinds of cards, the food responses at 9 hours were fewer than they were at 6 hours. This is to say that the food responses first increased with both kinds of targets and then decreased. The responses to chromatic cards decreased earlier than those to the achromatic.

The subjects in this investigation were not asked specifically to report on what they saw but, rather, to put into words the associations evoked by the blurred patches they saw on the screen. It is not possible to tell how close these associations were to perceptions. They might have been actual perceptions or they might have been several steps removed from "immediate behavior." Assuming that the subjects were reporting upon sensory impressions (or perceptions) and not secondarily evolved meaning, it can be concluded that the subjects' states had something to do with the characteristics of their perception.

Brozek, Guetzkow, and Baldwin (1950–1951) obtained opposing results in the responses of food-deprived subjects to ink blots. They found no preponderance of food-naming responses in such individuals. The apparent contradiction might rest on the very character of the ink blots, as in contrast to the blurred targets. The ink blots do not in any way predispose themselves to be seen as food articles. In the Levine, Chein, and Murphy experiment, other features of the investigation may have biased predisposition in the stimuli themselves toward being seen as food articles. There was no way for these authors to report just *how* ambiguous the targets were. It is possible that they could have been made more so, for all we know, and of course they could have been made less so. We do not doubt that under certain conditions persons deprived of food are more likely to perceive ambiguous material as food objects—that is, that perception becomes quite autistic in such cases.

It will be noted that ambiguity (nondefinitiveness) of the targets was a feature of both investigations. The use of such material can, at best, only produce responses indicating that when the observer is left free to "make something" out of visual targets, he is inclined to do so. No perceiver sees "nothing" when the material is so indefinite as not to force a given perceptual end result. Such experiments are examples of the principle involved in the traditional darkroom experiment in which illumination is projected onto a "white" (highly reflective) rectangular card. The card is seen as having a *size* and a *position* (distance) in space. All that is provided the viewer is a certain fixed size of retinal image. Since this same-sized retinal image will be produced by a large card far away and a small card nearby, the stimulus material is ambiguous, or shall we say ambivalent. The perception of the bright rectangle does not fail to be elicited just because the stimulus material fails to have in it the necessary factors to pin down the card's distance and size. Various features within the viewer that come under the heading "behavioral determinants" (Bruner, 1951) operate to make the determination.

Reward and punishment

The study of Proshansky and Murphy (1942) dealt with the influence of rewards and punishment on perception; the perception of the lengths of lines and the magnitudes of weights were investigated. Rewards and punishment in this case were devices to impose values on certain stimulus presentations they would not otherwise have. The experimenters imposed symbolic values or properties upon visual targets that under ordinary circumstances would not possess such properties.

A pretraining sequence of two sessions per week lasted for five weeks, during which several lines of different length were presented to the subjects. The same thing was done with weights that subjects lifted. After the pre-

training series was concluded, a second period, or training period, was begun. It lasted seven weeks, with two sessions per week. In this part of the study, the subjects were instructed not to make any overt response. They were simply to observe. During this training period, a reward was given for each long line and heavy weight shown to the subjects. For each short line and light weight, the subjects were punished: previous rewards were taken away from them. For the stimuli of intermediate physical value, reward and punishment were interspersed an equal number of times at random. A third period in the study consisted in the subjects again reporting their perceptions of length and weight, respectively, as the stimuli were presented. In this period, only the intermediate stimuli were presented. The object of the investigation was to see what influence the second period had upon the third.

For the control subjects, the first of the three periods was the same as for the experimental subjects. In the second, or training period, the control subjects were neither rewarded nor punished. They were simply presented with the lines and weights. In the third period, the two groups, the control and the experimental, responded differently. The control group showed no significant differences in perception in this period from perception in the first period. The experimental group, on the contrary, did show significant shifts in perception in the direction of perceiving the lines and weights of intermediate magnitude as similar to those that were always rewarded in the second period. It would seem that this is one of the more ingenious investigations on perception that has ever been conducted.

Rock and Fleck (1950) obtained negative results in using ambiguous figure-ground targets. Smith and Hochberg (1954) and others have obtained positive results. The fact that anybody achieved positive results shows that they are possible; we need, however, to know why failures occurred in any case. Journal reports cannot always give us the material with which to resolve apparent contradictions.

The individual's value system

Certain social psychologists maintain that the values of the individual tend to influence the duration thresholds at which materials related to these values are recognized. Postman, Bruner, and McGinnies (1948) gave the Allport-Vernon Study of Values to twenty-five subjects, obtaining their scores on the six value categories: religious, political, social, esthetic, economic, and theoretical. The subjects were given thirty-six words by tachistoscope, with each six words related to one of the six categories. The exposure times were at first very short and became increasingly longer until the words were correctly perceived. It was found that subjects responded correctly to shorter exposure of words belonging to the high-value categories. This, of course, was in line with the investigators' expectations.

The authors analyzed the nature of the incorrect responses made by

the subjects and grouped them as follows: the response words representing the same value category as the stimulus words themselves were called "covaluant responses"; the responses that represented an opposite meaning were called "contravaluant responses"; certain other responses were called "nonsense responses." Stimulus words in categories of high value to the subjects evoked more covaluant responses than stimulus words in less-value areas. Stimulus words in low-value areas evoked more contravaluant responses and nonsense words.

The same kinds of results were obtained in a similar study by Vanderplas and Blake (1940), in which the variable was the intensity of the sound of spoken words; consequently, the principle has, in a way, been demonstrated in hearing as well as in vision.

Perceived magnitude and value

The perceived size of an object is changed when size has some relevance to some need of the perceiver. The kind of evidence that is adduced for such a conclusion was first obtained by Bruner and Goodman (1947) in the following equipment. They used 10-year-olds to report on perceived sizes of coins by use of a spot of light whose size could be altered to match that of the coins seen in a different part of the visual field. A knob varying the size of an iris diaphragm was the means of varying the light spot. The coins used were pennies, nickles, dimes, quarters, and half dollars. The perceived sizes of all the coins were enhanced. The magnitudes of the overestimation increased for successive coin denominations up to the 25-cent piece, and then dropped somewhat for the 50-cent piece. A control group was given cardboard disks to use as standards instead of the coins. With these, there was essentially no overestimation. The values clustered around true size for each coin. A further comparison was made by using two groups of subjects, one from "poor" homes, the other from "rich" homes. The poor children "overestimated" the coins definitely more than did the rich children. When, on another occasion, the children were asked to imagine the sizes of coins, the poor children overestimated them. The exaggerations reported by the rich children occurred only for the half-dollar. Carter and Schooler (1949) redid the Bruner-Goodman study and failed to confirm the original findings except in the nonperceptual task of remembering coin sizes.

Ashley, Harper, and Runyan (1951) also repeated Bruner and Goodman's experiment, putting their subjects into different socioeconomic categories by hypnosis. Their subjects were adults, to some of whom they suggested while in the hypnotic states that they were "poor" and to others that they were "rich." While still in the hypnotic state, they were put through the process of reporting upon perceived coin sizes. The results confirmed the findings of Bruner and Goodman. As a control, the reports of the same subjects before hypnosis were used. The subjects saw the coins

as substantially their normal sizes. Not only were actual coins accentuated in size in the hypnotic series but so were slugs, whose metals were variously described as lead, silver, white gold, and platinum. They were accentuated in keeping with the value of the metal suggested and the suggested economic status of the subjects. Even remembered sizes of coins bore relation to value.

It is extremely difficult to evaluate such experiments and their results, since we do not know what goes on in hypnosis. Were we to think of hypnotic subjects as merely in a peculiar state of pleasing the hypnotist, and thus being under his control, then the behavior that turned out to be in line with his knowledge and expectations could not be used to support the kind of hypothesis implied in the experiment.

Another investigation in which social context has determined the nature of resulting perception is the study of Bruner and Postman (1948) that investigated the role of symbolism (value, again) in influencing visual perception of size. These authors used disk targets. One set bore a dollar sign, another a swastika, and a third a supposedly neutral symbol—a square with its two diagonals marked across it. The symbols were of equal size and were contained within a circle. The targets themselves varied from three-quarters of an inch to half an inch in diameter. The task of the subjects was to adjust the size of a circular disk of light seen elsewhere in the visual field until it appeared equal in size to the symbol-bearing disk. It was supposed that the subjects were oriented differently toward the symbols—positively toward the dollar mark and negatively toward the swastika. Ten subjects were presented the neutral and positive targets, and ten were presented the neutral and negative targets. Each subject made forty-eight trials, one-half with the neutral and one-half with the other targets.

The three symbols made differences in the perceived sizes of the disks. The disks with the dollar sign were perceived as largest, those with the swastika the next largest, and those with the square the smallest. This was true regardless of the various literal sizes of the disks.

If the patterns as symbols were to have made a difference in perceived disk size, one might have supposed that symbols toward which the subjects were negatively oriented might have been seen as smaller than disks bearing a neutral sign. This need not be the case, for any symbol toward which some distinct attitude is held might merely heighten perceived size. The most exacting critic might feel that there is a shadow of a doubt left in the experiment with reference to the sheer visual attributes of the three target configurations as *geometrical* forms. Both the dollar sign and the swastika are open forms, whereas a square with its diagonals is a closed form. What would have happened were the diagonals alone used for the neutral symbol? This might be submitted to test. On the other hand, we should not be so conventionally and rigidly oriented toward attributing vision to geometrical determinants alone as to refuse to believe that the symbolic character of a visual pattern has something to do with its perceived size.

Klein, Schlesinger, and Meister (1951) performed their own version of the Bruner-Postman experiment on the perceived size of symbolic targets. Their results did not represent a single marked tendency for all subjects but rather a set of consistent individual differences. It was interpreted that the size enhancement does not flow directly from some broad specified need but in the way that the specific individual is organized to deal with his needs.

Lambert, Solomon, and Watson (1949) set up a token-reward situation in which, by a conditioning process, poker chips that had no special value to begin with were used to obtain natural rewards. Their perceived size was retested and found to be greater than it was before the reward role was developed.

These experiments, although they do not rule out the possibility of geometrical designs having a spatial influence of their own on the perceived size of the disk targets upon which they are inscribed, do indicate that there is something that the individual perceiver contributes to his perceptions. This contribution shows up in perceived size, making it decidedly different from what would be expected where perception stimulus-bound. Although we do not know the mechanisms underlying its expression, the contribution has connection enough with what is otherwise expressed as "personality," "personal needs," or "personal values" to be attributed to these entities in certain specific situations. Of course, as a result, broad generalizations regarding perception are then made in such forms as "personal needs influence the sizes of perceived objects," for example. This does not mean that perception is fickle, and it does not mean that the ordinary psychophysical experiments on perceived size are to be discarded. The findings demonstrate that the differences obtained in the "social situations" and in conventional laboratory experimentation are the products of very different sets of conditions. Our understanding of perception ought to encompass both of these extremes of circumstance.

The use of the concept of need in explaining behavioral results is open to some criticism inasmuch as there are no criteria for determining what needs are and which ones are operating in a given subject in a given case. The concept of *need* is in as much need of verification as is the perceptual behavior under study. Without criteria for establishment of needs, anyone is at liberty to state a need at any time. The term ought to have more than a mere common-sense meaning. Even food deprivation is not always an ironclad need. Length of time since last food intake may, in a statistical way, seem to serve. But when results vary considerably, what is going to be the interpretation? We are not to be understood as denying that some concept of need might not be scientifically valid and useful, but it is certain that the term *need* cannot be made an explanation in an indiscriminate way. It can be said, in general, that the term has not been used carefully enough in many cases.

Nelson and Lechelt (1968) have performed an experiment on chil-

dren's discrimination of number that is an outcome of the previous studies on the discrimination of size as affected by socioeconomic status. They chose to study number (of items) rather than size and set up the following hypotheses.

1. Reliable differences will not occur in the perception of number (numerosity) between low and high socioeconomic children on the basis of monetary value when the number of items (coins, slugs) looked at does not exceed some critical number.

2. The actual monetary value of the coins will produce a numerosity bias in a given direction when a critical number of viewed items is exceeded.

3. Low socioeconomic children will differ progressively from the high socioeconomic children as the items of monetary value go beyond the ability of the sensory pathway to discriminate. This difference will be one of overestimation.

4. No differences will result between the two groups of children when slugs are viewed under any condition.

Actually, one factor the investigators saw in the situation of number estimation was a distinction between results determined primarily by the sensory mechanism and its limits and the results obtained when the limits of the sensory mechanism to discriminate number were exceeded. With numbers of items viewed beyond this critical limit, motivational factors could enter in.

Forty third-grade children in the city schools of Edmonton, Canada, were used, of ages ranging from 7 years 9 months to 9 years 5 months, with a mean of 8 years 6 months. The children were first given a questionnaire, in the attempt of the experimenters to define and distinguish between high and low "need." The pupils were considered equally familiar with "value" aside from their socioeconomic status. New Canadian dimes and aluminum blanks (slugs) were shown on a black velvet surface.

It was found that when the number of items exceeded five, the low socioeconomic children's estimations exceeded the estimations of the high socioeconomic group when the items were dimes. This difference grew as the number of dimes was increased from six to twelve. No difference was found in the estimates of the two groups when slugs were used or when the number of items was five or less.

Personality characteristics and autisms

It is said that the personality features of an individual predispose him to apprehend objects and situations in ways relevant to these features.

Schafer and Murphy (1943) made the following study to disclose the autistic nature of perception. They used an ambiguous figure-ground target

in which human faces could be perceived. To form the targets, circles were bisected by an irregular line so devised that either the righthand or lefthand portion taken alone could be seen as a face unambiguously. With the two portions of the circle taken together, the target as a whole was ambiguous. The righthand portion could be seen as a face, the lefthand as the ground field; or at other instants the lefthand position could be seen as figure (that is, as face), the righthand portion as ground field.

The investigation used two such ambiguous targets, in which, of course, a total of four faces was involved. The four face targets could be shown singly and were first shown that way in random order. From the experimenters' point of view, the targets were two pairs of faces; from the subjects' point of view, they were seen as four distinctly different faces. Each target presentation was made by a Whipple tachistoscope for an exposure of one-third second. The subjects were told that they would see faces in the exposures to be made, and before each target was presented the subjects were given a name to associate with each face they would see. The object was to learn the faces and their names. Finally, the two portions of the circle were put together, and then collateral conditions were manipulated to see whether the subjects could be predisposed to see one rather than the other of the two faces elicitable by the target. The subjects were told that when they saw *either* of two specified faces of the four they would be rewarded by 2 or 4 cents, and that each time they saw either of the other two of the four faces they would be deprived of 2 or 4 cents. In each trial, the subjects were told how much they had won or lost, and in accord with this they were to take from a pile of pennies the right amount or put back into the pile what was owed.

Five subjects were used, and all acquired the same set or bias in favor of seeing the rewarded faces for the first sixteen presentations, after which the perceptual process underwent what the authors called a process of consolidation. This process depended upon factors within the perceivers other than those controlled by the initial reward-and-punishment experiences. A control subject also acquired a set for two faces in the pretraining period.

Rock and Fleck (1950) obtained negative results in their experiments with reward and punishment with figure-ground stimuli. They found that their two-face components had a novel appearance when put together.

As is usual, when two different investigations of the same matter turn out oppositely, we have to suspect differences in method of instruction, in material used, or in the subjects themselves. Actually, it is differences in subjects that is one of the chief concerns of the social psychologist. The fact that Schafer and Murphy obtained the positive results they did under the conditions, as best we can understand them, leads us to the conclusion that rewards and punishments play a role in perception, such as in determining what will be seen as figure and what will be seen as ground. Often what is

ground and what is figure are taken to be largely controlled by structural factors. We know that this is not so in all cases. There are those in which there is ambiguity, as in the targets of the experiments just cited. Schafer and Murphy have shown that organismic contributions are crucial in determining figure and ground in such cases. Not only reward and punishment but autistic factors are influential.

Lindzey and Rogolsky (1950) presented twenty representative and six stereotyped photographs to 685 subjects, who were asked to distinguish between the Jewish and non-Jewish persons represented in the photographs. That is, they were to tell which were and which were not Jews, and in addition they were to indicate their confidence in the judgments they made. The subjects were also asked to fill out an Allport-Kramer Prejudice Scale. Five hypotheses that the authors held were substantiated at the 5 percent level of confidence: (1) the higher in prejudice (HP), as indicated by the Allport-Kramer scale, were more accurate in identifying the Jew and non-Jews; (2) the HP's labeled more faces Jews than did the less-prejudiced persons (LP's); (3) HP's indicated more self-confidence in their judgments; (4) the HP's were more accurate in identifying the stereotyped Jew and non-Jew faces; (5) HP's were more confident in judging the stereotyped Jew and non-Jew faces. One hypothesis the authors held had to be rejected, namely, that HP's report use of more "cues" describing Jew and non-Jew faces.

In their findings, the authors were able to abstract four additional positive items that are relevant here: (1) judges of high accuracy (HA) were more confident than those with lower accuracy; (2) those high in anti-Semitic prejudice reported less equal-status contact with Jews than those lower in prejudice; (3) HA's were also more accurate in judging stereotyped faces; (4) the mean accuracy of identifying the faces was significantly above chance.

Here we have a not unusual type of social experimentation. Obviously, one of the basic and crucial processes required of the subjects is visual perception. They had to look at pictures of faces in a discriminatory way, that is, in a way so as to make a two-category choice (judgment). The trouble with this investigation, as an example of social perception, is that it included far more than perception. It is an experiment in judgment, the utilization of a number of perceptions (immediate sensory responses) and certain other factors we have already mentioned in other connections. The subjects were obviously not curtailed in the time taken to make each of the separate choices. They could perceive and pause long enough to "think" about the faces as they were presented to them. Hence, the division of the faces into two categories, Jewish and non-Jewish, was very likely not solely a matter of perception.

We included this investigation as an example of the kind of studies that are often spoken of in dealing with social perception. It is not safe to

put such studies in this category without explicit qualifications. We do not know that perception itself was such a dominant factor in the choice responses that we can overlook the influences of other factors. For purposes of studying perception, the same investigation could have been differently conducted and would then have qualified. Let us say that the visual targets had been presented tachistoscopically and that the responses had had to be made within some limited span of time; they then could have been called "immediate responses" and thus perceptual ones. The question is, Would the end results have been the same, or different? We do not know. But until the two opposing ways of conducting the study are tried, we shall certainly not be at liberty to say that the nonimmediate response is for all ordinary purposes the same as the immediate or perceptual one.

Be all this as it may, we can be sure that a *certain class* of distinctions made by the subjects is perceptual, and that this was necessary before any judgmental choices could be made. That is, the subjects could not just as well have been kept from seeing the pictures in making the choices which they did.

DISTURBING STIMULI AND TWO ORDERS OF RESPONSE

Postman, Bruner and McGinnies (1948) produced a very frustrating situation for a group of subjects who were given a series of three-word sentences by means of a modified Dodge tachistoscope. The subjects were to report "what they saw, or what they thought they saw." This request is a typically phrased one, owing to the tendency of the naive subject to omit descriptions of perceived items with which considerable doubt is associated. It will be recalled, in this connection, that we earlier discussed the attribute of relative certainty in the perceiving process.

Each of the sentences was presented for various durations, some so brief that scarcely anything at all was seen, others long enough so that the three words were comprehended. Stated in other terms, each sentence was presented once for a duration of 0.03 second shorter than "threshold," once for 0.02 second shorter, twice for 0.01 second longer. Steps of 0.01 second in duration were added trial by trial until all three words were recognized.

The procedure for the first nine sentences of the total eighteen was the same for both the control group and the experimental group. At the completion of this part of the investigation, the experimental group was put into a perceptually frustrating situation. In other words, the subjects were called upon to do the impossible and were badgered in various ways by the experimenters as the study progressed from this point.

A black-and-white reproduction of a highly complex painting was shown to the members of this group. The subjects were instructed that they were going to be shown something that they were to describe fully. The

instructions were delivered in a very serious tone. The picture was exposed at a low illumination for only 0.01 second. None of the subjects could make anything out of the exposure except to discern a few vague contours and shadows. Remarks were made by the experimenters calculated to embarrass and belittle the observers for not being able to see something definite and detailed. During the ten or twelve trials the picture was shown, even the health of each subject's eyes as well as the state of his mind were brought into question. Control subjects were shown the same picture, but under favorable circumstances, including a 30-second exposure. During this time these subjects were given the same task as the experimental group.

The performances of the two groups were compared in terms of what was called threshold performances. If one word was perceived correctly out of the three, a one-word threshold was said to have been reached; if two words, a two-word threshold; if three, then a three-word threshold.

The control group improved, but the experimental group did not. Not only did it not improve but the sort of words it perceived from the material presented had some very illuminating characteristics. The words perceived pertained to the needs and curious circumstances in which the subjects found themselves.

McCleary and Lazarus (1949) made a study that is highly significant in a number of ways. They used ten five-letter nonsense words. For half of them, an unpleasant effect was brought about by accompanying the one-second presentations of the words with an electric shock. This evoked, among other results, a galvanic skin response, a symptom of autonomic disturbance. Following the establishment of a conditioned response to the five words, all the words were shown tachistoscopically for durations ranging from extremely short to just about long enough to recognize the words. The galvanic skin response was measured in each case between the time of presentation and the verbal report of what had been seen. Using only words that were correctly perceived (ones reported at subthreshold durations), it was found that the skin response was greater for the words previously accompanied by electric shock than for those not so accompanied. This is to say that even though the words' exposures were too brief to permit correct verbalizations (perhaps any sort of a perceptual response, from the conventional standpoint), they elicited the autonomic responses previously conditioned. This showed that although the presentation times were too brief for conscious discriminations, they were sufficient for another sort of discriminative response. Since the response has all the other characteristics necessary to fit our definition, we shall have to call it a type of perceptual response. The most significant finding of the study (if it can be taken at face value), of course, is that unconscious discrimination in the organism can occur and involves a less energetic impingement than a conscious discrimination of the same sort.

McGinnies (1949) used a list of eighteen words that were presented one at a time tachistoscopically to sixteen subjects, eight male and eight female. The words were presented for increasing durations, step by step, until they were recognized. In each trial, the subject reported what he thought the word was. Eleven words were neutral, and seven were critical. The latter were socially disapproved words, for example, whore, raped, bitch. Galvanic skin response was recorded in each trial. Duration thresholds for recognition of the critical words were greater than for the neutral ones. The galvanic skin responses to the words before they were fully recognized were greater for the critical than for the neutral words. The "misperceptions" (or misjudgments) for the critical words were less similar to the "right perceptions" than for the neutral words.

Here we have another example of much the same thing as in the previous investigation. It is as though a form of recognition occurs below what is called the recognition threshold, but it is such that possibly overt evasion can result. What we are talking about really is a lie-detector test. Whereas overt *evasion* can occur in verbal behavior, it cannot occur in the autonomic responses, such as the galvanic skin reaction. Might there not be a very different way of instructing the subject, and as a result might less discrepancy between autonomic and verbal end results show up? Might not new instructions be given after the regular thresholds for critical and neutral words were determined, and might the autonomic responses for such terms be recorded? These instructions would warn the subjects that they were not going to get by with evasions. They could be instructed to come right out with what they perceived the words to be just as soon as they could possibly hazard a guess. It might well be expected that some change in thresholds for critical words would show up. Under ordinary circumstances we should expect that subjects would require more "evidence" that a word is a nasty word before reporting what it is than would be the case for reporting "guesses" on neutral words. At least, we must rule out the "reluctance to report," or reluctance to hazard a guess on "tabooed material," as a factor before we can be fully sure of some of the assertions that have been made in interpreting the three experiments just cited.

The studies are open to speculations and criticisms, such as have just been made, by reason of the investigator's not having been quite as rigorous as the situation demanded in seeing to it that response was prompt. The needed form of investigation in these situations is a combination of tachistoscopic and a reaction-time experiment. It will be recalled that the classical *word-association test* was one in which recording time of response was crucial; for if, for any reason, evasion was attempted, it took longer to formulate a substitute response than to respond "honestly," that is, with the first word that came to mind. This difference became apparent at once and was interpreted as an evasion (a substitution).

HYPOTHETICAL CONSTRUCTS REGARDING RESPONSE

Social psychology that purports to be dealing with perception is well stocked with speculation regarding the nature of perception itself and with the mechanisms underlying it. There are several criticisms to be mentioned regarding these speculations.

1. Not all of either the experiments or the criticisms deal either exclusively with perception or with perception at all. This is true even though the material is brought into discussions of perception as though it were pertinent. As an example, such terms as judgment and cognition are used, sometimes more-or-less interchangeably with perception. This confuses the issue at hand and thus almost stalls the argument, as far as those who define perception as immediate response are concerned.

2. Hypothetical constructs seem to have been made too freely and in many cases represent how easy it is for those who believe something to believe that it is real. It is likely, however, that many of the intuitions of social psychologists are very insightful—could be substantiated were the appropriate experimental operations performed.

3. There is a tendency to couch many of the descriptions of mechanisms supposed to be at work either in ego or in perceptual terms rather than in terms of processes basic to them. It is not realized that perception cannot be explained or accounted for in terms of itself. This practice is but a special example of explaining by "cues," discussed in earlier chapters. In some cases, the explanations of perception have, in effect, called for a little perceiver within the observer to make decisions prior to the final act that is described as perception.

4. Perception, while not properly distinguished from judging and other processes, is restricted to the experiential and so-called sensory reactions and is not defined so as to include overt behavior. It is not clearly understood that motor processes may express the organism's relation to its surrounds. The conventional view seems to imply that "thinking" or "perceiving" comes first and then action. It is as if overt action is not a *mode* of perception but only a secondary expression of it. Our view is that action may *embody* all the perception that there is in some cases. At other moments perception is a highly conscious state, possibly with little or no overt sign of what is going on.

The foregoing criticisms would if observed help greatly not only in putting the study of social perception on a solid basis but in advancing it beyond the point at which we currently find certain other areas of perception.

Among the many terms that have been coined, or given a unique treat-

ment in the area of social response, are *selection, accentuation,* and *fixation.* They have been invented by certain authors and then taken up by others. What is meant by selection may vary, but at least in some cases it refers to the lowering of thresholds for "objects of distinct personal reference to the individual." Accentuation has to do with the appearance of objects as brighter, larger, and so on, than would be expected in the classical matching experiment. Fixation is the term given to the persistence and preferential retention of certain modes of perceptual response. The attribution of these three forms of behavior to needs and personality mechanisms makes up much of what is said about perception, judgment, and cognition by the social psychologists.

A host of other terms have arisen in connection with the idea of perception being selective and accentuational. For example, there are such terms as dominance, normalization, assimilation, vigilance, primitivation, compromise formation, schematization, hierarchy of thresholds, and degrees of personal relevance, value resonance, selective sensitization, not to mention others, all of which have been meant to have some technical meaning. One of these is *perceptual defense.* Other terms that go with it are *preperception* and *subception.* The first is merely a term that has been used by critics in describing the implications of the idea of perceptual defense. The second (subception) is a term that was seriously used by McCleary and Lazarus (1949) in accounting for the kind of results they obtained. In their investigation, they obtained discriminatory galvanic skin responses to words with shorter exposures than were required for conscious recognition of the words themselves. McGinnies (1949) describes such things as conditioned avoidance. Whereas there is no objection to having terms to indicate processes that occur within the organism and underlie the perceptual end result, it is important to know in what category these processes are supposed to take place. Are they neural or are they going to be in terms of still other hypothetical entities whose existence is as much in need of establishment as the processes to be explained? The tendency to build premise upon premise, each as hypothetical as the next, is all too often practiced in the more subtle areas of psychology.

Perceptual defense implies some sort of discrimination that precedes the discrimination that we call perception. To be on the defense, in the ordinary meaning of the term, is first to be able to determine what is threatening and what is not and, then, as a second step, to do whatever is required—as, for instance, in the case of reacting to words, to reject the threatening ones perceptually or treat them differently. Bruner and Postman (1947, 1948) among others are aware of the implication of using two steps to account for perception and that the mechanism carrying out the first step is about equivalent to having a little man within the perceiver himself. They state the matter in a dramatic way, saying that the experiments "suggest to the guileless investigator the image of the superego peer-

ing through a Judas eye, scanning incoming percepts in order to decide which shall be permitted into consciousness."

Various suggestions have been offered to solve the problem. Klein, Schlesinger, and Meister (1951) have suggested that "suppressor areas" in the cortex activated by autonomic innervation might have something to do with selection in sensory outcomes. Murphy and Hochberg (1951) suggest that the veridical aspect of percept formation with reference to externality is handled by the exteroceptive system. The authors suggest that in such cases the nonveridical or autistic aspects of the ultimate perception may be contributed by afferent impulses from the proprioceptors. This concept can be put to test to a greater or smaller degree and bears experimental investigation. We might suggest that it is with interoception or proprioception and not with exteroception that one's feelings of satisfaction, ease, comfort, and so on are most intimately connected. Accordingly, there might be some connection between tension experience and interoception, not between it and exteroception. The term tension is applied not only to feelings of concrete bodily tension but also to more diffuse experiences that relate even to one's orientation in social situations. It might be that the two uses of the term refer to a common denominator that is actually some process in relation to exteroception. Thus, whenever tension is involved it is always an interoceptively mediated affair. At times, the interoceptive components in the total activity may outweigh the exteroceptive ones, even in dealing with externality, and the perceptual outcome would be expected to be more particularly "evaluative" of the individual's orientation to the stimulus than is usually the case.

A functional distinction between the exteroceptive and the interoceptive seems to be related to what Werner and Wapner (1952) are trying to get at in their sensory-tonic field theory of perception. We live in our muscles and any perceptual theory must take them into account, even in dealing with experiences of externality, just as it takes into account the nervous system.

Bruner (1951) and Bruner and Postman (1947) have more to say about perceptual defense and the matter that some call subception. They suppose that the subject begins to recognize the generic characteristics of the stimulus, prior to complete recognition. In certain defensive perceptions, the subject often negates the nature of the actual stimulus in his response. This, they say, looks like a paradox at first. In order that the subject repress or negate a stimulus, it would seem that he must first recognize it for what it is. Bruner and Postman believe that this paradox can be obliterated if we do not restrict the definition of recognition to a single type of report—namely, a veridical one—and if we do not insist that all responses about which we talk depend upon prior recognition (see Bruner, 1951).

Now let us see how these cautions are to work. The authors say that to

a stimulus there can be tripped off a constellation of response tendencies, among which veridical responding is only one. Others may be tripped off as well and be very effectual in leading to other responses. Each of the possible tendencies is said to have its own threshold. This is determined both by the stimulus and the directive state of the organism. The directive state is otherwise labeled as the differential availability of the responses in the organism's total repertory. They believe that to make this idea work the threshold of affective avoidance is often lower than for veridical report, although it may be the other way around in some cases. When so, "correct" recognition must take place prior to affective response.

We add an illustration here that seems relevant. It is not greatly different from the elements that were involved in Bruner and Postman's (1947) incongruity investigation; it is only simpler. If a blank card is used for a target in a dark room and is the only part of the visual field that is visible, the experimenter may ask the subject how *far away* the object appears to be. He will get an answer. But we can later find that the answer has had some connection with how large the object was taken to be. The task of the subject might instead have been that of looking to see how *large* the seen object appeared to be. In this case, we could have found, by subsequent operations, that the perceived size had some connection with the distance at which the object was taken to be. *One* of the factors seems to be involved as a premise for the final outcome, and the *other* factor is the perception, or final outcome itself. We can say, then, that the *task at hand* is one of the factors that determines the way the internal activity ingredients are involved in relation to each other. The task at hand, as represented within the organism, determines which will be premise and which will be conclusion. This task demand, of course, is represented to a large degree in what Bruner (1951) and his colleagues call the directive state of the individual at the moment.

Bruner and Postman (1947) assume that recognition requires a process of interconnection between an incoming "stimulus" and a "trace." The matter, they say, can be stated in stimulus-response terms by saying that an incoming stimulus, in order to evoke a recognition response, must develop a connection with some response mechanism. The next assumption is that not all traces are equally "available" to the development of the connection with response processes. Deprivation, punishment, disuse, and the past history of the organism might be factors leading to this relative unavailability. They also include need states and states of expectancy in accounting for availability.

Bruner and Postman say that when a stimulus is in line with the prevailing state of the organism, it is recognized more readily. Put into our language, it would be said that all impingements are dealt with by the organism in ways dependent upon what is occurring in the organism at the instant. Some impingements will be quite ineffective in evoking perceptual

response. Some impingements will be reacted to without delay (that is, with minimal latency); others will be slowly reacted to. Some impingements can be utilized in the internal ongoing process and will evoke perceptions of familiar objects, whereas, in the great majority of other instances, the impingements would not evoke such perceptions at all. Hence, we have two problems: the quickness of response and the kind of response. If the internal state of the organism is "not favorable," a much more intense or long-lasting impingement will be required to evoke any response.

We all agree with Bruner and his colleagues that from start to finish there is something hierarchical about the processes that are involved in developing what comes out as an experiential perception or as an overt act of recognition or choice. Just so long as we hold to envisaging these factors in other than perceptual terms, and thus keep away from language that should be confined to describing the perceptions themselves, we are on the proper path. The terms we shall have to utilize, although they may not as yet be used by neurophysiologists, will ultimately fit into their understandings.

There are still other experiments that are related to the question of subception, although they do not throw light on the mechanisms at work. Wispe and Drambarean (1953) obtained word-perception thresholds for terms related to biological needs (hunger, thirst, and so on). They found that words connected with these needs were recognized at a lower threshold after a period of deprivation than otherwise. The deprivation did not carry its effect indefinitely. Twenty-four hours did not seem to be any more effective than ten hours. These authors interpreted their findings in terms of the hypothesis theory of Bruner and Postman and the stimulus-response learning theory. Hypothesis theory is the assumption that all perceptual and cognitive processes take on the form of hypotheses set up by the organism or evoked at the time. Hypotheses seem to be more or less ready-made orientations so structured as to require further experience to validate or disprove. The failure of the further experience to fit the hypothesis results in unclear object structuring or other unclear features of perception. Hypotheses change and the testing process goes on. This is something like the statistical averaging process assumed by the Ames transactional theory of perception. Word responses signifying personal acts instrumental to need satisfaction were found to decrease by the end of the ten-hour period and to increase with twenty-four hours of deprivation. McClelland and Atkinson (1948) interpreted their findings as showing that responses related to instrumental acts for need satisfaction increased as need increased.

An investigation was carried out by Bricker and Chapanis (1953) in which they used guessed responses to nonsense words presented tachistoscopically. After the first two wrong guesses, fewer trials than needed by chance were found to be required to perceive the words "correctly." They used a very simple and convincing interpretation for their findings. It was

merely that what is incorrectly perceived under the conditions of the experiment conveys some information. They state that information conveyed prior to recognition comes from partial aspects within the stimulus target. They thus attempted to by-pass the notion of subception, although it is not easily understood as to how they thought this was accomplished.

Certain other writers also reject the notion of subception. Perhaps the term itself does not sound suitable. Howes (1954) declares that with certain fairly reasonable assumptions such data as those of McCleary and Lazarus (1949) can be predicted better on the basis of *probability theory* than by subception. We have indicated that subception does not need to mean just one thing. It has to do with a set of processes, whatever they are, that goes on prior to the emergence of the end result we call perception. It is simply a way of labeling the antecedent processes rather than couching them in personalistic or psychoanalytic terms and looking to processes on some level of functioning different than perception for the roles required to provide the end result. Undoubtedly chance plays a role, chance here being but a fortuitous concatenation of circumstances. Surely, however, there is more to it than mere fortuitousness. When one uses probability theory to explain something, he had better inspect his assumptions to see the nature of the *loading* they contain. The loading may contain the same elements that were rejected in the theory that probability is supposed to supplant.

Bruner and Postman have resorted to the concept of adaptation level, a mechanism postulated by Helson (1948, 1951) to account for perceptual end results that are found in classical psychophysical experiments. Bruner and Postman make the use of adaptation level only a matter of words. They simply talk about the adaptation level for valued objects being higher than for others. To be able to say this, they involve the concept of a "trace system." This system that accounts for memory is supposed to operate on the adaptation principle. Thus in perceiving, or let us say judging, a valued object, the stimulus is "assimilated to the higher adaptation level" and as a result the object appears large. First of all, we must here be careful of what we are attributing to the stimulus and what to the perception, so as to avoid the caution we have on other occasions mentioned—namely, explaining perception in terms of itself. This caution can scarcely be offered too many times. Second, the phrase "assimilated to the higher level" does not mean much either as a concrete description or as a testable hypothesis.

Duncker (1939) performed a study in which a leaf-shaped target made of green felt was exposed to his subjects in spectral illumination. The long wavelength, or "red," end of the spectrum was used. The leaf target was matched with a comparison target so that they looked alike in color. Then a very differently shaped target seen as a donkey was cut out of the same green felt and shown to the subjects in the same illumination as the leaf target. This target was matched for color and the match was found to be different. There are various reasons why this match might call for a green

different from that of the first target, but let us suppose that all the necessary precautions had been observed; it showed that the leaf was seen as greener than the donkey. Bruner and Postman state this as "an assimilation to the adaptation level for the color of a green leaf, an adaptative level built up in course of the experience of the human species with green leaves." Does using adaptation level add any understanding to the matter here? Can we find what green it is that is the adaptation level—the green that is the green of the leaf? It would seem that actual operational use of the concept of adaptation level is confined to experimental situations in which the adapting conditions are known and measurable.

PERCEPTION AND SUGGESTION

At the beginning of this chapter, we mentioned that one form of social perception might well be the perception that occurs under social conditions. In other words, perception might operate differently when other people are around and when they are absent. Although it might be difficult to be sure what effect is being dealt with, it is something that is worth knowing about. Of course, effects in such situations are assigned to distraction or to changes in the character of attention or to suggestion. Experiments can be set up so as to let the effect of the proximity of others operate, or they can be set up to give the subject moment-to-moment indications of how others are actually behaving. In the latter case, the process that is customarily said to be operating is *suggestion*, although the word does not constitute an explanation.

For some reason or other not much work that would be useful to us on this topic is available. The nearest to it, for example, is the work of Sherif (1935) on the autokinetic phenomenon, mentioned previously on several occasions. It is obvious that there is the utmost ambiguity in such a phenomenon. Even when the observer is making his observations alone, he is not sure at all instants whether there is any movement of the light he sees or just in what direction or at what rate the movement is taking place. It is obvious, then, that there is little in the stimulus that can guide the observer. The main ingredients for the perception lie in the observer himself.

Sherif used this ambiguous situation to compare the performances of individuals working alone and in groups, the groups consisting of three subjects working together. The subjects reported upon the number of inches they saw a spot move. In each case, when the subjects worked alone, they differed significantly in the amount of movement perceived. When they worked in groups and were aware of one another's behavior, the amounts of movement were less extreme. Those who saw the most movement when working alone saw less when working with others. The same thing happened with subjects who saw the least movement. They, too,

moved toward the mean. We have to wonder exactly how the subjects performed and how their perceptions were recorded. The reports could have been of genuine perceptions or they could have been something else.

INDIVIDUAL DIFFERENCES: SOCIAL OR BIOLOGICAL?

Among the individual differences that have been found in perception are those that Witkin and his colleagues (1954) found in their extensive work on the perception of the vertical and horizontal. The first of the several tests in which sex differences in perception were found was the rod-and-frame experiment. In it a luminous frame was seen by the subject as a surround for a luminous rod that the subject was required to set so as to represent the true gravitational vertical or the true horizontal. The subject was in either an upright position or supported in a leaning position 28° from the vertical. The subjects almost always adjusted the rod away from the true vertical toward the tilt of the frame. The women, however, tended to tilt the rod to an even greater extent than the men. This was true both when the subjects were upright and when they were tilted. It was concluded that women tend to be influenced more by the visual field than the gravitational field.

The tilting-room tilting-chair test was the second set of conditions into which the subjects were put and in which the men and women differed in their responses. Both the chair in which the subject was seated and the room within which the chair was placed were rotatable around a common axis, which permitted tilting the subject to the right or to the left as he faced forward. (See Chapter Thirteen, page 375.) When the subject's chair and the room were tilted and he was required to reset one or the other to the true vertical, the following occurred. In the parts of the study in which the room had to be made upright, most subjects were influenced in the visual direction of the field, that is, in accordance with the appearance to them of what they saw. The vertical of the tilted room tended to be the true vertical to them. Actually, the adjustment represented a compromise between the vertical of the room and true gravitational vertical. In general, the women accepted the room's vertical as the true vertical at more extreme tilts than did the men.

In the portions of the study in which the subject (with eyes closed) was required to bring his body to the true upright, it was found that most subjects did pretty well in aligning themselves with the true vertical. No sex differences were apparent here. When a tilted visual field was present, the result was much different. Subjects generally had to tilt themselves away from the beginning position toward the tilt of the room in order to perceive themselves as truly upright. The women, here again, were more extreme than the men. The results indicate that in the perception of the

surrounding field and of body position, women tend to be more strongly influenced by the visual field that is acting at the moment. This is to say that they are less able to distinguish between body position and field position.

The third test that Witkin and colleagues report upon is the rotating-room test, in which the room in which the subject was enclosed was rotated and he was also tilted. The subjects had to readjust room and chair so that they would be in the true upright position. Most subjects had to return their bodies and the room in the direction opposite to the displacement so as to perceive them in the upright position. The women had to make less of this return adjustment than the men. If the men and women had their eyes closed when this adjustment was being made, they came out with substantially the same results, but not so with their eyes open. The women tended to align their bodies with what was visually upright rather than with what was gravitationally upright. In all the cases in which the men and women differed, the women were more influenced by visual than by postural factors.

The next test to be described was the *auditory-visual conflict test.* The instrumentation for this was so designed that the sound of the voice of the experimenter could be shifted to the right or to the left as the experimenter remained directly in front of the subject. The subjects were to indicate when the sound of the voice no longer seemed to come from the experimenter. With eyes open, both sexes allowed the displacement to be considerable before they lost the sound to the center position. Here again men and women differed. On the average, the men permitted a 64 percent increase in the displacement, and the women permitted 109 percent increase, over the displacement allowed with the eyes closed.

The next test was called the *embedded-figures test.* In it, a hidden figure within a geometrical pattern was used as a visual target. Men on the average required significantly less time to recognize the hidden figure. Out of the twenty-four hidden-figure patterns, all but two were recognized in less time by the men. In the test as a whole, there were eighty-eight failures by women as against thirty-five for men. Here, again, the structure of the field was utilized differently by the men and women.

In another type of test, the subjects were required to match two similar items, the one in shadow and the other not. This test was administered in two forms. In these tests the women showed a slight but not statistically significant difference in tendency to be more influenced by the field surrounding the targets than did the men.

In all the foregoing tests the women and the men differed. This would be called a sex difference. Our question is whether this is really biologically a sex difference or one that is socially derived from differences in the social environment of boys and girls. Many, many differences that have first been attributed to the biology of sex have turned out to be differences that have been derived through the process of living. In the present experiments we

do not know what to attribute the differences to. We have included them here in the belief that they are probably a demonstration of socially derived differences. They might belong just as well in the chapter on the development of perception (Chapter Two).

THE HONI PHENOMENON

A phenomenon that can well be considered to have a social origin is the Honi phenomenon. In Chapter Seven the nature of the distorted rooms devised by Ames at the Dartmouth Eye Institute was described and the results were explained. The Honi phenomenon is simply an unexpected deviation from the usual response. A few years ago, a woman observer saw the face of her husband at the one window and the face of a stranger at the other. The size change, as usual, was reported for the face of the stranger, but not for her husband. In 1952, Wittreich made a study of this phenomenon that has come to be called the Honi phenomenon, after the family nickname of the woman observer just mentioned.

Wittreich performed two experiments. The first involved ten married couples, providing twenty observers. Six of the couples had been married less than a year, the others for from two to ten years. Distorted rooms of two sizes were used. Viewing was monocular in all cases. In using the small room, each observer was asked to describe (1) the room, (2) the hands of the experimenter that were put through the two windows, (3) a marble that rolled across the floor, giving the appearance of rolling uphill, (4) two cases of two people showing their heads at the two windows (one case with two strangers, the other with the spouse as one of the two people).

The experiment with the large room was somewhat similar. Among the ways it differed was to have the observed persons walk across the room after first having been seen standing in their respective corners.

In the small room experiment, six of the twenty observers reported a difference between the appearance of the spouses and the strangers. This difference was in the expected direction. In the large room experiment, seven of the twenty reported a difference in the expected direction. At no time was a difference in the unexpected direction reported and at no time was the spouse reported as changed in appearance more than the strangers. One member of all the couples married less than a year manifested the phenomenon in one or the other of the two rooms. Only one of the observers married more than a year reported the phenomenon.

The criterion for the Honi phenomenon in the large room where the observed persons walked from the corner to the center of the back wall was that little or no distance had to be covered before he or she became normal in appearance. The magnitude of the difference in the distance walked by the spouse and the stranger was used to portray the strength of the Honi effect.

Whereas the small room served to show whether or not the Honi

phenomenon would appear, the experiment with the large room was an attempt to quantify results. In the second room the differences obtained in the appearance of spouses and strangers were significant. The attempt to relate the strength of the Honi phenomenon to length of marriage failed, however. No explicit explanation was offered for the results. It was pointed out, however, that the explanation will have to be "something more than just a consideration of the perceiving mechanism and the stimulus configuration."

CONCLUSIONS

Perception, the sensory response to stimulation, is, to say the least, modifiable. Just what the specific principles are that underlie the flexibility of this kind of behavior are not known. A great deal of speculation has been made in recent years regarding causation. This has been more intuitive and verbal than actually substantiated and usable in a scientific understanding. To have brought the perceptions that occur in definitely social contexts under investigation and to have demonstrated the fluidity of this kind of behavior have, nevertheless, been great contributions to psychology. Psychology has been reawakened to the significance of perception in everyday behavior, the kinds of contexts under which perception will commonly be studied from now on have been broadened, and the student of perception has been liberated from a kind of near-sightedness summed up in the quick use of the phrase "perception is stimulus-bound."

The transactional outlook on perception, which certainly is closely akin to the various outlooks expressed by definitely social psychologists, has expressed the idea of the purposeful character of perception, and should be thought of in connection with social studies.

SUMMARY

This chapter on social perception opened with a discussion of what is social about perception and what perception is social and whether it differs essentially from perception that is not social. In reviewing investigations in the area of social perception, it was found necessary to caution the reader that not all the supposed investigations were direct studies of perception but some were studies of *judgment* and as such must be distinguished from those that actually conformed to the definition of perception.

The chapter was mainly given over to reciting various investigations that have attempted to show how perception is influenced by social considerations or the needs of the perceiver.

SEVENTEEN

The Nature of Perception

⁂ The nature of perception was only briefly discussed in the introductory chapter because it seemed appropriate to move without delay into presentation of experimental work on the separate senses. Having completed this presentation, we are now ready to deal with perception somewhat more fully.

Whereas much of what is known about perception has been obtained by studying the sense modalities separately, this is not the only approach. Two other approaches, for example, are helpful. One is an attempt to determine how the sense modalities are functionally interrelated. The other is the examination of stimulus-response behavior from the standpoint of gross environmental demands. Whereas in the sense modality approach the organism's capacities to respond to separate forms of energy are analyzed in light of four criteria discussed earlier, in the environmental-demand approach an entirely different set of considerations is involved. In this procedure, only the more pervasive aspects of nature are taken into account as primary factors. For example, one of these is, How does the organism react to gravity? All the sensory mechanisms involved in this are regarded as a unit and are called a *perceptual system*. Immediately one realizes that several sense modalities are inescapably involved. They are studied as they act together to meet environmental demands and the goals of the organism.

In this chapter we discuss the perceptual systems after describing the kinds of studies involved in the older forms of "interrelating the various sense modalities." Once the nature of the several perceptual systems has been briefly described, we shall set forth various features of perception in general, including features of attention and vigilance. Helson's list of characteristics of perceptual response and Allport's list of the phenomena

of perception will follow. Consideration will also be given to the types of information about perception that can be gained from body process and brain anatomy. The chapter will conclude with a brief description of the more prominent theories of perception and a discussion of perception's symbolic nature.

RELATIONS BETWEEN SENSE MODALITIES

Since it has been customary to deal with the various sense modalities separately, one at a time, any mention of their similarities, mutual interaction, or plural involvement has been in the form of *putting them together*, thus a combining process. This direction of approach has become so ingrained in the common outlook that skepticism is often expressed in response to assertions that the modalities are not actually as separate as generally described. When one asserts that the term *brightness* can be used as appropriately to describe a sound as a seen surface, grave doubt is evoked and controversy tends to be aroused.

One need not regard the sense modalities as initially separate entities. Instead of beginning with body structures in the adult, which we know are distinct and diverse, and proceeding as if sensory experience were dependent wholly upon the mechanisms confined to the modality in question, we may begin with the early organism. We may utilize the findings of the embryologists—namely, that the tissues of the mature organism develop by differentiation from the tissues of earlier stages.

Adult diversification of tissue into body organs, including the several kinds of sense organs, occurs through a developmental process, and the development of sensory responses is to be regarded in the same manner. The experiences the adult calls vision, hearing, touch, pain, taste, smell, and so on, did not originate as totally different sorts of response and then gradually fuse but, instead, developed from something less distinct into the variety of modalities and separate sensory experiences that characterizes the adult.

There are certain facts that are difficult to explain by the first view. One, for example, is *synesthesia*, the most common form of which is "colored-hearing," the experience of visual phenomena when the stimuli are acoustic rather than photic. Colored-hearing is not a case of the subject transforming or translating auditory experiences into visual ones, or having auditory experiences accompanied by secondary visual experiences, but rather of having the primary end result occur in a form characteristic of a sense modality whose sense organs are not directly impinged upon.

According to the second view, this end result might come about by the failure of the underlying mechanism common to both modalitics to differentiate properly in the course of development or, after having differentiated well enough for the subject to be able to have experiences in both

modalities, to suffer some distortion and anomaly of further development. Sometimes a blind person will develop synesthesia of the colored-hearing form. Possibly overall shock, along with the deprivation in one modality, may lie at the basis of the development of the synesthesia.

Kinds of studies in interrelating the senses

Since much of the work in dealing with sensory interrelation has been done from the standpoint of the first view, we shall give attention to it at this point. The work can be classed into five categories: (1) study of associative participation of secondary modalities, and study of synesthesia, as one example; (2) study of intersensory facilitation and inhibition; (3) study of the manifestation of the same property or quality by two or more sense modalities; (4) study of common performances in which a number of sense modalities participate; (5) study of performances that are called senses but instead are general functions that do not satisfy the criteria for being unique or separate sense modalities or, for that matter, senses at all.

These categories need some clarification. Associative participation is the activity of sensory mechanisms not directly activated through their sense organs, when a given sense modality is impinged upon. Let us say the tactile mechanism is directly impinged upon by coming in contact with a surface. The response involves not only this mechanism but the visual cerebral mechanism even when the subject is blindfolded. For example, the subject may attempt to "visualize" the item touched or felt. Likewise, the kinesthetic mechanism may be involved and thus influence the perception of size. In synesthesia the sense modality stimulated may be audition. But instead of simply hearing something, the person sees something as well. This seeing is primary and vivid and is not only a sense experience but a vehicle for expressing meaning just as words (auditory items) are for the usual person.

Intersensory facilitation and inhibition are the end results evidenced by the fact that directly activating a second sense modality, while activating the first, changes the responses stemming from the first modality. It may reduce thresholds, or it may raise them.

The third category, in which two or more kinds of sense experience are describable by a single word, is illustrated by the case in which both visual and auditory experiences can be called bright or dull. That is, a surface of a visual object may be bright, and a sound may also be said to be bright.

Certain bodily functions, such as maintaining posture and coping with gravity, are accomplished by means of several sense modalities. To maintain posture in a gravitational field, or to determine what is the experiential vertical, involves the vestibular sense, the muscle sense, vision, touch or pressure, and, in other cases, hearing.

It is sometimes said that organisms have a time sense. The use of the word sense in this way is certainly different from the way we are using it in the present discussion. Perceiving time is not based upon a specific set of sense organs, a peculiar kind of stimulus, a specified and separate afferent pathway, although it does consist in a unique kind of experience or a unique overt relation to externality. It is an accomplishment of the organism that may be expressed in immediate behavior (a perceptual response), or it may be manifested in conceptual ways.

Associative participation

Each sense modality provides for two functions: a direct experiential result ensuing from stimulation of sense organs and an associated result, one familiar form of which is imagery. Imagery is the experiencing of objects and all that pertains to them, either by way of memory or by way of participation with some modality that is being activated through its own sense organs. We may call this latter form of imagery *associative imagery.* We seldom hear a sound, for example, but what we imagine, to some degree or other in visual terms, what the sound source is. It is a natural part of the hearing of sounds to identify their sources, and this identification includes visual imagery. There are times when the visual components of the overall experience evoked by acoustic stimuli do not have to do primarily with imagined sound sources but rather with other meanings. Spoken words are the best examples. This is also true in music, where color and visual and kinesthetic movement predominantly may enter in.

There seems to be a fraction of our population able to use visual imagery to carry the major meaning of acoustic stimulation. There is some temptation to call such persons synesthetics (or synesthetes), but we should prefer to reserve this term for those whose whole perceptual and cognitive behavior is compellingly photistic even when the original stimuli are acoustic rather than visual.

Karwoski and Odbert (1938) and Karwoski, Odbert, and Osgood (1942) studied photistic visualizers among student populations. Of the 276 subjects studied, over half fell into the class of photistic visualizers. They found that exciting music may be pictured by the photistic visualizers as etched bright-red forms. While many other people verbalize auditory impressions in visual terms, there is the tendency on their part to say that these visual phrases are metaphors. When such terms as bright, fiery, luminous, filmy-thin are given to what they hear, they feel the words certainly are appropriate but at the same time disavow them as being anything more than verbalisms. The very fact that they have the appropriateness they do is some testimony in favor of the substitutive ability of one modality for another, particularly the use of the visual modality for the auditory and the tactual. It would seem that a considerable degree of this

ability to substitute is subject to intentional learning, once the individual becomes sympathetic to the idea. Karwoski and Odbert found that many of the photistic visualizers could point to their first marked synesthetic-like experience. In many cases, it turned out to be a traumatic occasion in early life.

Some of the persons in question characteristically imagined the entire visual field as uniformly colored, the various hues succeeding each other as the music progressed from one tempo to another. Others described multi-banded fields in which the bands were in motion in time to the music. Qualitative features of the music as related to what is ordinarily experienced as timbre were expressed by various horizontal layers of the bands. It was also found that the geometry of visualized figures reflected the music's tempo. Fast music was reflected in sharp and angular figures, and slow music gave rise to large rounded forms. That the associations just described are not uncommon suggests that perhaps those who make them do not deserve to be rigidly set aside as a class.

Some individuals are truly synesthetic. In some persons, stimulation through the auditory mechanism produces very definite visual effects, the outstanding feature of which is some sort of color experience that carries meaning in and of itself. Voices and other sound stimuli are often seen in visual imagery by the blind. As was said earlier, the process is not primarily that of hearing and then translating the sound into a learned color. The color itself emerges immediately and with meaning for the synesthetic individual. Blind persons may identify people around them from voice, but when they do so in terms of the colors evoked by the voice rather than in terms of auditory quality, they are synesthetic.

Whereas chromesthesia, or colored-hearing, is the most common sort of synesthesia, there are other forms such as colored-tasting and colored-smelling. So far it has been impossible to demonstrate that synesthetes possess any set of unique or peculiar neural connections that would account for the behavior. Hence, so far, we must suppose that the achievement comes about through the mechanisms potential in everyone.

Intersensory facilitation

The idea of intersensory facilitation is based upon findings and interpretations in physiology. We now turn to some examples of interaction found in the laboratory. Child and Wendt (1938) reported that a brief photic pulse would lower auditory threshold most when it preceded the acoustic stimulus by a half second. This was corroborated by another worker. This result might be attributed largely to attention. But even though it is admitted that attention plays a considerable role, it does not necessarily destroy the argument that the senses are greatly interrelated. Attention is the name given to an overall organizational pattern in the

behaving organism that focuses its activity in some certain direction. If the use of a photic stimulus can succeed in realigning the behaving individual so as to react more sensitively to a second stimulus, it demonstrates a kind of interaction (though indirect) between the stimuli pertinent to two modalities.

Kravkov (1939), much interested in the interrelation of the senses, believed that an acoustic stimulus would raise the excitation level of the central nervous system and thereby facilitate the "irradiation" of white surfaces through this process in the visual cortex. According to the classical expectations of visual irradiation, acoustic stimuli, in increasing irradiation, should make a white area between two black ones more visible than otherwise and a black area between two white areas less visible. Kravkov found that a 2100-c.p.s. acoustic source did increase the acuity of black on white and reduce that of white on black as expected. Hartmann (1933), who studied the same problem, stated that improvement occurred in both situations, not only in one. In contrast to these two workers, Serrat and Karwoski (1936) failed to find any facilitation.

Interrelation in the lower senses

Probably the best evidence for intersensory relations is to be found in the lower sense modalities, such as taste and smell, modalities that are not very articulate in their properties in the first place. In many cases, the experiences elcited can scarcely be designated as those of smell rather than taste or vice versa. The main criteria for experience lie in whether a substance has been placed in the mouth or, for example, something is experienced as a result of sniffing.

Hahn and Günther (1932) carried out an important line of experimentation on the role of thermal stimulation on taste. They brought the tongue to the temperature of the taste solution they would subsequently use and maintained it constant as long as needed. Most purely chemical reactions are enhanced as temperature rises. But in taste, enhancement occurred only for the sweet substance used, and it even reversed above 37° C. Different subjects as well as different sweet substances show unlike curves in relation to temperatures. We must fall back on something other than solely chemical reactions at the taste cell to account for temperature effects.

The work of Hazzard (1930) in the analysis of olfactory qualities is a good example of the involvement of several senses in what is ordinarily labeled as the behavior of a single sense. His findings had to do with dimensions of smells that do not often become verbalized nor perhaps even recognized in everyday descriptions. These dimensions had to do with texture, volume, brightness, other spatial features, and the temporal courses of the experiences. The scales on which the observers ordered their perceptions were heaviness-lightness, looseness-tightness, smoothness-

roughness, softness-hardness, thinness-thickness, dullness-sharpness, brightness-dullness, liveliness-inertness, surfaceness-deepness, and smallness-largeness. It would appear that the observers were allowing themselves to include aroused imagery in their reports on where the various odors lay along the various dimensions. Supposing that such imagery is an intimate part of the immediate reaction, it can be said to be a feature of the perception.

PERCEPTUAL SYSTEMS

The various ways that sense modalities cooperate with each other have just been described, but from a traditional standpoint, in which a given modality is taken as primary and the other modalities are studied for the possible influences they might have upon it. A very different mode of approach is possible, consisting in: (1) dealing with the prime ways the organism has of actively carrying out purpose by way of sensory mechanisms and (2) using the gross demands of the environment as a reference. Piéron (1952) was one of the psychologists who believed there are only five modalities of sensory attention. Boring (1929, 1942) has always held that there are only five senses. J. J. Gibson (1966) has recently come out with the description of five perceptual systems as *looking, listening, touching, tasting-smelling,* and *a form of basic orientation.*

It would seem that if one is examining perception from the standpoint of possible systems, these five do not quite complete the list. There seem to be kinds of environmental forces acting to discommode the organism. It is not only that the organism must react in some way to be effectively ambient in a spatial-mechanical world but also to maintain its own internal equilibrium. This is generally spoken of as *homeostasis*. There is a sensory (or perceptual) side to this matter, which we shall call *maintenance of bodily comfort*. This perceptual activity may possibly be looked upon as a sixth perceptual system.

Perceiving involves attention, motor adjustments, and exploratory movements, all of which have long been a part of the study of psychology but seldom considered to be a part of perception. Gibson at times makes them a part of perception but, at other times, he treats perception in the more traditional way, thus *separating perceiving from acting*. We would say that perception and action cannot be declared separate processes. Action is as much an expression of relationship to the environs as the experiencing of sensory quality or as immediately "understanding" something.

As soon as one faces the matter of active relation between the organism and the environment, he can at once see body systems in action. For example, following Gibson, one can speak of an *eye-head* system, an *ear-head* system, a *nose-head* system, a *mouth-head* system, and a *hand-body* system. This way of classifying is a frank recognition that eyes, ears, and the other organs, ordinarily called sense organs, function not in isolation

but in connection with orienting and exploratory activities of organs or tissues closely related to them. One of the essential features of our definition of a sense organ was that a sense organ is made up of two sorts of tissue, neural and nonneural. The nonneural tissue performs two functions: the initial and more direct reception of the impingements and the orienting, adjusting, and exploratory feature to the extent that this occurs. Speaking of an *eye-head* system is but an extension of this dual-tissue concept and includes more than the traditional boundaries of the eye or the eye and its extrinsic muscles. It includes all that can be observed to be active when the given sensory function is being manifested. In the sense of touch, it can immediately be seen that the whole surface of the body is the nonneural part of a gigantic sense organ. This is not the traditional way of looking at the matter, but it is in keeping with the best understandings of the day.

While the unitary view of perception espoused in this book makes no issue of the differences between muscles and the sensory pathways in expressing the interrelations between the organism and its environment, the conventional view has always made much of it. Thus, we may pause long enough to list certain muscular systems involved in the organism's reactions to the environment, because these reactions are bound up with what (even according to convention) has been called perception. Gibson lists them as the *postural, orienting-investigating, locomotor, appetitive, performatory, expressive,* and *semantic* systems. These systems, according to ordinary language, are involved in *doing* something. In contrast to this, we do not distinguish them from perceiving systems that also can be said to be *doing* something. Looking at the list, it can be seen then that it implies the *functions* perception fulfills, perception being not merely a passive form of "observing" the environment.

Our next step is to examine the five perceptual systems mentioned at the beginning of this section. Two features are involved, a description of (1) the overall set of conditions that the organism encounters and of (2) the overall complex of processes involved in reacting to these conditions. These descriptions will now definitely transcend the purely energistic descriptions appropriate for describing the relations between impingements reaching sense organs and the patterns of neural activity that are elicited. We have already implied that various levels of description are needed to describe the organism just so long as these descriptions are used in their appropriate places and are not unwittingly intermingled.

The basic orienting system

This system has to do with orientation to the direction up-down and to the plane of the ground. It includes detection of the stable and permanent framework of the environment. The primary energistic manifestation of force is gravity. The primitive sense organ for this was the statocyst,

which was essentially a sac filled with fluid and lined with receptor hairs sensitive to mechanical force. These hairs were acted upon by an object (such as a ball or stone) depending upon the orientation of the statocyst in the gravitational field. Such an organ was sensitive also to sudden pushes applied to it. In the present human vestibular apparatus with its semicircular canals and an otolith component, the combination distinguishes accelerations from steady postures in the gravitational force field. Higher organisms have, of course, brought into play muscles that control organs that make contact with supports (such as the ground) that must act in relation to the vestibular mechanism. This is a perceptual system that is perpetually involved, although this is not evidenced by constant specific sensory experiences. Much of the activity of the system is thus a good example of the fact that perceptual activity need not be experiential (that is, involve specific sensations).

The auditory system

The auditory system, too, had a primitive beginning. It would seem that this system was first able to respond to *shaking*, a vibratory event. While both the present-day vestibule and the crucial element of the auditory system (the cochlea) are sensitive to mechanical events, the auditory system has become specialized for a rapid rate of shaking, a kind of micromechanical event that is called acoustical. (Conventionally, this is called *sound*, but we have reserved that term for what is *heard*.) The vibratory events occur in the atmosphere and may be transmitted to various solids such as the bony structure of the head (the skull) within which the auditory mechanism is situated.

These micromechanical events are exceptionally useful to the organism in determining the nature of what is happening external to it. Each class of events produces its own pattern of vibrations. Thereby the organism can distinguish between such natural situations as thunder, waterfalls, the wind, rolling objects, collisions between objects, and many more. Many of these classes are of fundamental importance in the daily economy of various animal species, including man.

Vibratory disturbances are propagated in such ways that in connection with the receiving mechanisms, direction, distance, as well as intensity can be discriminated. In this discrimination, motor activities such as the organism's orientation of the two ears to receive equal energies of input are involved. Not only are the nonbiological features of nature capable of initiating acoustic vibrations but so are animals of various species. Since such emissions (or vocalizations) can be controlled and utilized in the interests of the vocalizer and the listener, the auditory system ranks high in usefulness.

The haptic system

This is the system by which the organism is literally in touch with the environment. The events or facts detected have to do also with the organism itself, such as the detection of its own mechanical properties. Here again, in this system, no single modality is involved. The accomplishments of this system accrue from the interrelated way that several modalities participate.

This system includes the whole body—its muscles, joints, and skin. The sense modalities involved are touch, kinesthesis, and possibly temperature and pain. The system involves not only *detecting* but *doing*. Gibson calls it the kinesthetic system, thus using the term kinesthesis in a way somewhat different from what is customary: He defines it as the *detection of movement*. It is the information-provider for bodily movement; thus kinesthesis is something that cuts across the sensory systems. He says that there are many kinds of kinesthesis—joint kinesthesis for the body framework, vestibular kinesthesis for the movements of the skull, and cutaneous kinesthesis for movement of the skin across what is touched. Finally, there is visual kinesthesis for perspective transformations in the visual field. Let this not confuse the reader. Kinesthesis is still the name conventionally given to a single sense modality, the muscle and joint sense.

The taste-smell system

One of the first things to be reminded of here is the unitariness of the sensory impression when one puts a familiar article of food into the mouth. Analyzed into its components, it will be found that several sense mechanisms are involved: gustatory (taste modality), olfaction (the smell modality), touch, and temperature. At times, pain may also be aroused. The situation can be looked at in two ways. The traditional way was to assume that separate sensations of all these modalities are somehow elicited but fused and that with this are involved memories of the past, the final result being, let us say, the experience of tasting an apple. According to Gibson, no such thing occurs. The performance is instead the obtaining of a kind of information pertaining to apple-eating. The immediate and direct experience is that of having some apple in one's mouth. To extract the sensory qualities implied by the activation of the separate sense mechanisms involved requires special effort and is sometimes difficult. The reader will understand by this example what Gibson means when he says one does not go through the business of first experiencing sensations (sensory experiences specific to each of the several modalities) as a prelude to experiencing the apple substance in the mouth.

Many substances are exceedingly different in the experience (the taste)

they produce when one or another of the modalities is occluded; hence, we know that such modalities are ordinarily participating. If Gibson is correct, there must be an invariant detected by the person doing the tasting if he is to experience the substance so as to identify it.

Even vision generally enters into the taste experience, as is demonstrated by having a person close his eyes and open his mouth so that another person can put something into it. The taste experience is quite different from that when the material is seen and identified as it reaches the mouth.

What has just been said about tasting applies to smelling. Some gases (the stimuli for activating nasal membranes) can be tasted. Thus, in some natural situations, one is hardly able to say which is taste and which is smell.

The visual system

We come to another perceptual system in which the mechanisms that constitute it are not primarily for the production of sensation, but according to Gibson, rather to provide for perception—the utilization of information. While the primary feature of the environment involved in vision is radiational (that is, photic), the information is not fully significant without the action of certain mechanical receptors that have to do with motion and bodily contact as in maintaining posture and contact with a "ground" and in tactual exploration. The photic information provided depends upon whether the organism is on land, in water, or flying in air.

Whereas some decades ago dealing with composite sensory behavior in the manner just suggested would have been virtually ruled out, we are coming to the point nowadays at which this approach is beginning to be considered quite necessary. Adopting it must not be looked upon as an abandonment of the information obtained by the analysis at the single-modality level.

The system for seeking and maintaining bodily comfort

The perceptual systems that have already been described have primarily to do with reacting to externality in a way that the comfort system does not. They refer to objects or to conditions and events in the environment.

The comfort system is directed inwardly toward the organism itself. As far as certain things we know about certain sense modalities, this is not saying anything new. We merely point out that the activity is perceptual and is to be regarded as expressing the activity of a system.

One feature of the perceptual systems is the involvement of positive action, such as search and manipulation, rather than only a passive receptivity to stimulation. Since the organism is able to feel bodily discomfort

and distress as well as well-being, it is not to be assumed that these experiences are only passive matters. The individual is just as truly goal-directed in seeking comfort as in seeing, touching, and hearing. The main difference between this perceptual system and the others is that no specific sense modality has been traditionally isolated for expressing overall bodily comfort. But it does not matter, for all the other perceptual systems involve more than one sense modality. The general orienting system is most like the comfort system, inasmuch as it primarily involves the vestibular mechanism that produces no specific sensations or any experiences until some extreme circumstances are met with.

Traditionally, receptors have been classified as: (1) *exteroceptors* such as eyes, ears, and skin, which inform the possessor of external events; (2) *proprioceptors* such as the receptors in muscle, tendons, and joints and the vestibular mechanism, which inform of position, contact, and movement; and (3) *interoceptors*, which inform of visceral conditions. In maintaining bodily comfort, both proprioception and interoception are involved. Thus mechanoreceptors, thermoreceptors, pain, and chemoreceptors are involved. That such matters have been studied scarcely, if at all, as the activity of a system in no way precludes their being regarded now as features of a perceptual system, coordinate with the other perceptual systems.

A major problem that immediately arises is whether the sensory effects of ingestion of chemicals is to be thought of as involving chemoreceptors or as producing a form of pain. Various spastic conditions, which of course are mechanical, seem to have some very pervasive and subtle effects on the way the individual feels and much needs to be done to trace the basis for the extreme uneasiness that results. Such uneasiness is not simply a matter of pain, as in cramps, but is a general sick feeling that sometimes arises with spastic and other untoward mechanical states of the alimentary canal.

Modes of general orientation to the environment

It is appropriate to take into account the general orientation, state, or mode of ongoing activity of the individual as a basis for considering what perception will be like at a given instant. Although little or nothing is said in the literature about this matter, it is quite thinkable that such a way of dealing with perception would be realistic and fruitful. There seem to be wide differences in the individual's general modes of activity. One mode is the *active* or *motor* mode, illustrated in a football game in which the behavior of a player is primarily ambient and energistic. The player is involved in quick observations and shifts in performance dependent upon what he sees; what he sees is expressed virtually entirely in terms of what movements he makes, which way he runs, pivots, hesitates, stops.

The second mode might be called the *appreciative*. In this state, the perceiver contacts externality in a very different way. A prime example is

that of visiting an art gallery or attending a concert. These are extreme examples, but the mode is uppermost in many periods during a typical day for many people. It involves qualitatively experiencing sights, sounds, tactile surfaces, tastes, and aromas. These not only involve sheer sensory impact but may include imagery and other cognitive features.

The third major mode that often characterizes the individual is the *contemplative* state, in which he is withdrawn from sensitive and critical contact within the instant-to-instant features of the environment.

It would seem, then, that in analyzing perception it would be quite appropriate to take these modes into account. To do so would be one way of recognizing what is already tacitly assumed by many, namely that perception is an outcome of not only environmental input (stimulus) conditions but the ongoing processes within the organism.

SELECTIVITY, ORGANIZATION, AND MAINTENANCE: ATTENTION

Attention, clarity, and vigilance

Three additional aspects of the relation of the organism to its surrounds should be mentioned. One is the fact that perception is selective. It is not a complete forthright response to all impingements reaching sense organs at any given instant. Another is the dimension of structure or organization of the response itself, whether motor or experiential. When perception is studied as conscious content, the matter emerges as a consideration of levels of *clarity*. These factors taken together are called *attention*. The third relevant aspect pertains to how long and under what conditions perceptual response is maintained at a given level or is equally well elicited and is dealt with under the title of *vigilance*. In some ways attention and vigilance are closely entwined. Sometimes vigilance is thought of as a form of attention. Investigators of one of the three considerations are often interested in the others also.

One of the earliest matters of interest concerning attention was the question of how many things one can attend to at once. Various experiments were conducted in the attempt to settle this question. The experiments in which multiplication of items were used as objects of attention did not settle the matter as clearly as expected. The conclusion mostly drawn after all was that one can attend to only one thing at a time. The issue really centers around what is a unity and what is a multiplicity. One of the most noticeable features of attention is its short duration and variability.

Attention has long been classed as involuntary and voluntary, this division, while a perfectly natural way of proceeding, has not proved as sophisticated as it seemed. Using the term *voluntary* brought in the classical

entity or function called the *will*, an item seldom directly talked about these days in experimental psychology. The voluntary-involuntary dichotomy is, at bottom, simply a recognition that the factors determining attention lie both in the organism and outside of it.

Attention and expectation

Expectancy plays a role in perceptual response, sometimes referred to as attention. For example, Siipola (1935) told his subjects that they would be briefly shown words that pertained to animals and then showed them letter groups such as "seal" and "whale." They often responded with seal and whale. On the other hand, when the same groups of letters were presented after telling them that the words would pertain to boats, the responses were often "sail" and "wharf."

Broadbent (1958) found in a study of vigilance that there was a sharp decline in efficiency of detecting an "echo" on a radar screen when it was dim and hard to see but little decline when it was intense and clear. Increasing the duration of a repeated signal and increasing its frequency and regularity also tended to prevent decline. When a strong continuous acoustic impingement was presented along with the visual signal, greater decline in efficiency occurred. Many such experiments have been accompanied by interpretations more-or-less dependent upon the person making them.

A number of studies on vigilance and attention have been related to the activity of the reticular activating system of the brain. The activities of this system seem to be connected with the arousal of awareness and the maintenance of vigilance. Haider, Spong, and Lindsley (1964) studied computer-averaged cortical responses to "nonsignal" photic stimuli and to randomly interspersed "signal" stimuli. The latter required overt response and, therefore, the efficiency level as a function of time could be measured. The response was thus taken as an indicator of vigilance. The object of the investigation was to measure both vigilance and the size of the evoked cortical potential that was a neurophysiological indicator of seeing the signal. As detection efficiency (vigilance) declined as a function of time, the amplitude of the cortical responses to *nonsignal* stimuli decreased and latency of response lengthened. Corresponding changes were found in the cortical responses to signal stimuli and attentiveness (vigilance). A further finding was that "more specific lapses" of attention, as indicated by failures to detect, were accompanied by average-evoked cortical responses of lower amplitude to undetected as compared to detected signals.

Spong, Haider and Lindsley (1965) made a similar study in which both photic pulses and brief auditory inputs were used on humans. The subjects observed flashes and clicks that alternated. In some cases, they were asked to attend to the clicks; in other cases they were asked to attend to the

flashes. Occipital cortical responses to the photic inputs were larger when subjects attended to the flashes than when they attended to the clicks. The same principle was true when they attended to the clicks. The temporal area cortical responses were larger when the clicks were attended to.

CHARACTERISTICS OF RESPONSE BEHAVIOR: HELSON

Helson has pointed out seven basic characteristics of behavior, pertaining to perception as well as behavior viewed otherwise. Serious examinations of the nature of perception should include an awareness of them:

1. Bipolarity of response. The organism is selective in its behavior, avoiding some forms of stimulation and approaching and accepting other forms. The bimodality of this is accented by the fact that there is an intermediate category to which the organism is neutral and to which it can be said to be adjusted.
2. Pooling, interaction, or integration of elements. Various modalities act together in producing perception. (This we have already discussed in dealing with perceptual systems.)
3. Differential weighting of stimuli. Selectivity is expressed in what we have called discrimination: There is no sure way to predict how an organism will react by simply examining the features of impingement: The determinants lie within the organism. As yet nothing is known in neurophysiology that will account for this differential weighting of sensory inputs.
4. Nonlinearity of response. Response and energistic input do not possess a one-to-one relation. "Over-reaction" to small inputs and "under-reaction" to intense ones is a common feature of nonlinearity of response.
5. Variability and oscillation. Two forms of irregularity show up in repeated responses to constant or repeated inputs. The first is random and arises from random determiners. The second manifests characteristics that cannot be attributed to chance. Helson calls the first random variability and the second ordered variability. Some ordered variability is a form of response to changes in the general level of illumination.
6. Optimal levels or ranges of function. Helson has referred to the manifestation of this as the U-hypothesis. For example, when performance is measured in errors or time, the graphs of performance, as a function of the independent variable, turn out to be somewhat U-shaped.
7. Output and input matching. This broad characteristic is illustrated by the following examples. The level of photic adaptation is a weighted mean of all the luminances and chromaticities in the visual field. Physiological zero for thermal conditions coincides with the ambient temperature. Heaviness, as we experience it, corresponds to a weighted mean of the items being lifted.

THE PHENOMENA OF PERCEPTION: ALLPORT

When perception is considered as an experiential affair, there are several classes of perceptual phenomena. Six classes are distinguished by Allport (1955): (1) Perceptions have *sensory qualities and dimensions.* Examples in vision are hues. The other modalities provide us with other qualities. These qualities possess intensities and strengths. (2) Perceptions possess formal properties such as *shape, outline,* and *grouping.* We might call these structural properties, or features of composition. (3) *Constancies of appearance,* such as lightness constancy, shape constancy, and size constancy occur in the appearance of visual objects. (4) A *dimensional frame of reference* exists in the way things are experienced. The observer, for example, is able to call something large or small not in the absolute sense meant in class 1. (5) The *emergence of concrete object character* relates not to the size, brightness, and so on of a segregated experience, but to the uniqueness of "whatness" of the unit dealt with. (6) The *prevailing state* of the observer refers to the principle of modes we have already pointed out.

CONCEPTS OF PERCEPTION ARISING FROM THE STUDY OF BRAIN FUNCTION

Certain insights into perceptual behavior may be obtained from the findings and concepts of those who deal with brain anatomy and process. The technique of ablation of brain parts to find the effects produced on behavior has been used for several centuries.

No single brain part plays a highly restricted role. It is involved somehow or other in a number of behavioral outcomes. Nevertheless, some center may be crucially involved in a given type of behavior while others play very minor roles. Strictly "localizing" function has long been a temptation in describing the central nervous system.

One may use the general procedure of anatomy and physiology as a starting point or one may resort to it while studying an example of behavior. In using it as a starting point one may suppose that the various classes of behavior that will emerge as the result of the crucial participation of a given brain center ought to have certain features in common or be more alike than behaviors that are not all crucially affected by disturbing the brain center in question. By some such reasoning one might study the brain mechanisms involved in the various sense modalities. For example, if he found that center x was crucially involved in the sense of smell (olfaction) and also crucially involved in behavior that is called emotional, one might suppose that in the evolution of the organism smell may have come to possess an emotional characteristic. That is to say, smells may possess an emotional tinge beyond any such thing found for another sense that did not seem to involve the common crucial brain structure.

Comparative studies up and down the animal scale have contributed toward furthering insights. In this broad investigational endeavor certain relations between activities that would otherwise be undreamt of have been disclosed. The implications that perhaps some sense modality is more like a nonsensory mechanism than it is like some other sensory mechanism may be far reaching. At least one may be led to a different appreciation or concept of that mechanism.

This principle is significant in examining the behavior phenomena resulting from the work of Klüver and Bucy. In 1938, they described some visual consequences of ablating the temporal lobes and the temporal rhinencephalon (nose-brain) of monkeys. This was followed by further investigations regarding the other consequences of this operation. Removal of the areas mentioned produced a rather definable set of behavioral symptoms that came to be called the Klüver-Bucy syndrome.

The features of the syndrome (Klüver, 1958) were: (1) Visual agnosia, consisting in the animal's loss of ability to discriminate the meaning and significance of visual inputs (ordinarily resulting in the seeing of objects) from visual criteria alone. For example, the operated animal could not detect that an "object" was dangerous or edible. This deficiency may be manifested in other sense modalities, also. (2) Oral tendencies, tendencies to examine (contact or manipulate) items with the mouth. Some animals may use the mouth without even picking up items first. (3) A strong tendency to notice and touch every item in sight. (4) Diminution of overt expressions of emotion. Items that normally excite fear and avoidance are neutrally accepted. (5) Great increase in sexual behavior (hetero, homo, and auto forms). (6) Changes in dietary habits. Whereas normal animals are vegetarian, operated monkeys begin to consume large quantities of meat.

Although the syndrome is obviously not defined exclusively in terms of perceptual activity, there is considerable about it that is perceptual. Since the rhinencephalon (or part of it) was included in the ablation, the operation involved the olfactory mechanism. Since certain visual functions were altered in the operation, it was important to ascertain what they were and what could be said about them. Are the characteristics of vision disclosed those that are generally ascribed to vision, or are they something new?

The term rhinencephalon has not always been applied strictly to the same brain structures. Territorial extension has involved functions other than the sense of smell. Other terms also came to be applied to the brain region in question. Broca (1861) called the region the "great limbic system." MacLean (1949, 1958) has also used the term "limbic system" for a certain group of structures in this region. Experimentation has shown that the region is involved in the emotions and sex. The limbic system is part of the old brain while it is the new brain, for example, that contains the projection area for vision. The common involvement just mentioned poses

the question of what olfaction, emotions, and sex have to do with each other. What may the three have in common?

Olfactory phenomena are highly variable and intangible. Odors are not experienced as objects, making them quite different from experiences in some of the other senses, visual experiences in particular. For example, Helen Keller, who was dependent solely on tactile and olfactory impressions, found that what she touched seemed to be real. Her tactile impressions had definiteness and permanence. But what she smelled did not reside in anything objective. Odor was nothing external to her but merely an experience in her nose. Odors came and went and were completely elusive and did not provide a spatial world for her.

Klüver pointed out similarities between the characteristics of odors as sensory phenomena and the other two behavioral functions focused in the limbic system. He identified olfaction more closely with these functions than with vision. He pointed out that olfaction does not provide for transpositions such as are found in audition, as when tunes are changed from key to key, and in vision.

It has been traditional, of course, to class some senses as *proprioceptive*, or pertaining to the body and its state, and other senses as *exteroceptive*, or having to do with the external world. But olfaction has not traditionally been called a proprioceptive sense. The sighted individual has been able by various indirect means to ascribe odors to various external sources, and this has led to some of the essential characteristics of olfaction itself being overlooked. It seems to have taken the neuroanatomical approach to have brought out certain of its overlooked characteristics.

Years ago, one psychologist classified the human senses into the two categories of the *defining* senses and the *intimate* senses. The latter do not define objects but instead produce evaluations of desirability and attractiveness or their opposites. The characterization of senses in this manner is relevant in the present context. Klüver pointed out that the parts of the brain that subserve olfaction, sex, and emotions have to do with the variable features of behavior, while other parts of the brain have to do with "constancies."

The geniculostriate system mediating vision provides for perceiving constancies in the external world. Through this system the world is a world of objects, things with identifiable properties that do not disappear or lose their identity despite the rather extreme variations of input to the system.

Herrick (1933), the noted neurologist, observing the lack of localizing function of olfaction, despite its being an exteroceptive sense, suggested that the olfactory mechanism may cooperate with many other systems or serve as an activator of the nervous system in general. Other investigators have made somewhat similar suggestions regarding certain parts of the limbic system. The amygdala, for instance, has been suggested as modulating the autonomic, somatic, and behavioral mechanisms. Some of this modulation is in the form of damping or blunting or otherwise regulating

the effects of external impingements before they can become effective. Klüver suggested that the variable functions of the limbic system are poised between the processes giving the *external* environment a stable appearance and the processes of the diencephalon stabilizing (making constant) the activities of the *internal* "environment."

In pursuing the solution of the intricacies involved in the relation between the organism and the environment, one deals not only with percepts, memory images, and eidetic images but also with pseudohallucination and hypnogogic images, for example. The variability implied in these terms is possibly predominantly mediated by the temporal lobes and the limbic system, if some of the above suggestions regarding differences of function of various parts of the central nervous system are to be relied upon. To solve such problems, more than the purely phenomenological approach of the nonbiological psychologist is needed.

THEORIES OF PERCEPTION

A number of theories of perception have appeared in the literature. They are more nearly statements regarding outstanding functional features of perception than they are theories of its overall character. Thus, each one brings to attention some aspect that others do not or formulates the same features somewhat differently from the others. Nevertheless a complete picture cannot be achieved merely by combining the theories.

Core-context theory

This classical theory emerged in the days in which perception was thought of solely as an experiential or conscious response. According to it perception is a group of several types of interrelated parts. The elements consist in simple sensations integrated with images or ideas left from past experiences. According to the theory, sensory components do not, in themselves, have meaning, whereas perception, the aggregate, does. Sensations are combined into an aggregate under the laws of attention and certain principles of sensory connection. Images from past experiences are also part of the aggregate. Some of the sensations form a *core* or focal group. The remainder of the constellation provides the context. From the aggregate, meaning emerges. Meaning is a contribution that the images and sensations provide each other. That is, meaning evolves out of *context*, or, more directly, context is thought to be meaning.

Texture-gradient theory

This theory was formed to account for the spatial features of visual perception and, like other theories, has specifically to do with only limited features of perceiving, visual perception in this case.

The theory accounts for seeing the third dimension in space by the very same means as for seeing the two dimensions of a plane. It points out the orderly relations between the projection of the image of a surface on the retina and the orientation of that surface with reference to the line of regard. Surfaces at right angles to the line of regard provide for projections (images) of uniform texture. Tilted surfaces provide for images of graded texture. The portion of the surface nearer to the eye is represented in the image by coarser texture, portions lying farther away by fine textures. This texture gradient, then, is the correlate of third-dimensional perspective. Artists and draftsmen have utilized its principle for centuries in their two-dimensional drawings. It remained only to translate it into a clear verbalized understanding for use in scientific circles. This was done only recently by Gibson (1950).

According to the theory, perceived objects are not aggregations of sensations of pointlike units but are constellations of surfaces and edges. Edges are formed by abruptions in gradients, and corners are formed by vortices from which gradients extend. Perceptions are not copies of external objects but are certain kinds of correlates of energistic arrays. Retinal images are neither replicas of the world nor pictures that perceptions copy but patterns of variations possessing lawful relationships to externality.

Cybernetic theory

In the cybernetic theory of perception, the known facts of the nervous system and the principles used in the construction of electronic computing machines are brought together in the attempt to account for the organism's overall achievements we call perception. A major problem dealt with is how the experience of form is preserved despite differences of position of projection of objects on the retina, resulting from various eye movements. Another question pertains to how a pattern may be transposed—that is, how a melody can be recognized despite its being played at various positions up and down the pitch scale.

The cybernetic theory of McCulloch and Pitts (1948) employs the facts of accommodation (focusing of the lens of the eye), convergence, and adaptation (an analogue of volume control) in conjunction with other known or imputed processes in the nervous system to accomplish the essential tasks apparently performed in perception. Such mechanisms as negative feedback, scanning, and memory (or "storage of information") are used to bring about within the nervous system transformations of conditions lying outside. Thus, external events are reconstructed within the organism and integrated with stored information derived from previous inputs. Since many features of perceptual behavior can be brought to enactment in electronic machines, the machines are used as models of the principles supposedly used by the organism.

Cell-assembly-phase-sequence theory

This is a view of how perception becomes what it is in the adult organism. Hebb (1949), the author of this view, believes that convincing evidence indicates that the initial response to visual targets is not nearly so complete and well integrated a process as the Gestalt psychologists seem to assert. While this does not define the nature of the process called perceiving, it describes how perception is a product of learning. The idea of piecemeal building up of perception through the incorporation of various cell groups in the brain into larger and larger patterns of organized activity is somewhat opposite to the older idea of equipotentiality that had been advocated by Lashley (1929) to explain a number of experimental findings and common observations. Equipotentiality is the name given to the supposed interchangeability of various portions of the brain in bringing about the same behavioral end result, be it an experience or a motor end reaction. Hebb's theory attempts to whittle perceptions down to what is initial and original and to what is the product of learning. It states that initial reactions to a visual presentation give rise to exploratory motor components that play the role of sequentially building up activities of small groups of brain cells into a larger sequence of activity—the neural bases for the activity we know as perceptual in the adult organism. Certain forms of activity of neural circuits (reverberating circuits) provide for prolonging the activity in the cell assemblies so that additional repetitions of the stimulus can become effective in the individual's attainment of a fuller response to it.

The experience of the figure-ground dichotomy is thought to be somehow primary in perception. The experience is very different from experiencing *identity* between objects. Identity comes only later. Patient repetition is required to activate all the possibilities in the way things look. Separate attention to parts of figures is required at first.

Adaptation-level theory

This theory, by Helson (1964), attempts to deal with the organism's response to configurations in accord with *dimensional* or *quantitative* order. The adaptational process underlies the individual perception of sizes, distances, intensities, and other magnitudes or even qualitative properties such as beauty. The theory indicates that in order to behave this way the organism establishes a neutral or indifferent zone in the gamut of its encounters with the environs. This is used as the frame of reference. The evaluating process proceeds on the physiological as well as the psychological level, though generally it has its basis below that of conscious judgment formation.

Motor-adjustment theory

This outlook upon immediate response, typified in the thinking of Freeman (1948), emphasizes the motor posture or set of the organism at the time of stimulation. Hence, this outlook, too, centers on the character of the organism's contribution to its interaction with its surrounds. The description of behavior begins with postulating a covert pattern of tensions in skeletal muscles that precede the overt reaction of the muscles. This set, since it involves muscular tensions, provides a backlash input into the central nervous system by way of the proprioceptive pathways. This determines, to a large degree, the state of the nervous system at the time of receiving exteroceptive stimulation, that is, stimulation through eyes, ears, and so on. This tension consists in two components: a general background of diffuse and pervasive tension of all muscles, including the postural musculature, and a specific component, different in amount in various specific groups of muscles. Thus the tension, in general, is a pattern with a focus or foci. The percept, then, is the immediate overt action that takes place in relation to external event and is a part of the homeostatic regulation of the organism.

Sensory-tonic field theory

This is an attempt to include in response to the environment certain motor aspects that are generally overlooked by other accounts of perception. We saw in the two preceding theories some recognition of the participation of muscular activity in perception, but neither of them included all the possible motor aspects of perceptual response. The sensory-tonic theory is cognizant of one of the typically neglected features and attempts to bring it into the description of perception. The word tonic, in this theory, applies not only to the usual tonic features of postural sets but also to the major aspects of phasic muscular activity involved in skeletal movement. Tonic seems to refer at times to the tonic *experience*, at other times to the physiological system in which tension conditions exist. Werner and Wapner (1952), the proponents of the sensory-tonic theory, were concerned with how exteroceptive and interoceptive factors interact. Both factors seem to be involved, and neither can be neglected in understanding the organism's reaction to its surrounds.

To achieve this interaction, a process prior to both sensory and motor behavior was postulated and stated as a "total dynamic" process. Sensory and tonic factors are contributing components by reason of their possession of "common dynamic" properties. For example, stimuli that act upon the organism asymmetrically can be shown to set up unequal degrees of muscular tonus on the two sides of the body. This asymmetry is transformed into

some tendency to perceive differently the positions of lines and other targets when no asymmetry of muscular tone is involved. Thus, visual experience is partly regulated by the tonic asymmetry produced at the time.

Probabilistic-functional theory

This theory centers on the phenomena of perceptual "constancy," in which "cues" form a considerable explanatory role. It is said that the organism, in line with the requirements of biological adaptation and using available data, tries to "reconstitute" the object and is able to approximate it. The object it reconstitutes is an intermediate one having properties somewhere between those of the "*real*" object and the stimulus pattern *received* by the sense organ. Brunswik (1947), the author of this theory of perception, calls it a probabilistic functionalism, for the object as perceived is never better than an approximation and represents a probability.

Transactional theory

This theory, although developed quite independently of Brunswik's, also includes the idea that perception represents a probabilistic end reaction. Perception is, as theorizers Ames (1953) and his colleagues sometimes say, *prognostic*. This theory gives a central place to the purpose or directionality of the perceiver and looks upon perception as a guide to action. The action is for the furtherance of the organism's purposes. The theory states that the organism infers the nature of the object by an unconscious judgment of what physical object would most likely be required to produce the present pattern of impingement on the sense organs. The theory has been built up largely on the study of physiological optics, in which it is recognized that a number of physical targets are capable of producing the same pattern of retinal image. Hence, the organism is confronted with a choice, and perception may or may not be veridical.

This theory involves the recognition that past experience plays an important role in perceiving. This pertains not only to specific objects but to the nature of the world in which the organism finds itself. Certain assumptions, as it were, result and perception occurs in accord with them.

Directive-state theory

Developed by Bruner and Postman (1948), this theory is one of the earlier forms of social psychology's contribution to perception. Perception is based upon two sharply contrasting factors: the structural and the behavioral. They are given the labels of *autochthonous* and *behavioral*, respectively. The determinants of the first sort are the stimulus, the effects of the impingement on the receptors, and the various pertinent parts of the

nervous system. These are the innate or fixed and unchangeable possession of the organism as a mechanism for perceiving. They are primarily dealt with by the Gestaltists and those who apply psychophysics as a mode of experimentation. The factors can be said to be formal or formalistic.

The second set, the behavioral determinants, stem from higher-level processes having to do with other features of psychological activity. These processes carry the effects of past experience in general and include the organism's needs, tensions, value systems, and biases. This theory indicates that the individual as a whole is represented in his perceptions, whether this representation can be said to be synonymous to personality or whether some more specific and tangible mechanism can be detected as elicited by the given stimulus situation. Be that as it may, the behavioral determinants form a central directive state making perception other than solely the often-described stimulus-bound end result.

Hypothesis or expectancy theory

This theory by Bruner (1951) represents a later form of social psychology's contribution to perception. It recognizes the fact that perceptions do not arise from blank neutral ground and states that the sets that the individual displays are what might be called hypotheses. As a rule, the subjects' sets are long established and firmly embedded. The theory points out that the stronger the hypothesis is, the greater is the probability of its activation in a given situation and the less stimulus information will be needed to activate it. The theory speaks of confirming and infirming the individual's hypotheses.

Gestalt theory

This is a view of organismic activity that disavows the very logic that was used to construct the core-context theory and all similar forms of associationism. It is a form of emergence doctrine in which the unit is not a building block but rather a complete product, a house itself. The theory specifies how the house comes into existence and, more especially, how it operates once it exists. These formulations are generally known as "laws of Gestalten." One hundred and fourteen or more such laws have appeared in the literature from time to time, but later writers have attempted to reduce this number to a much smaller list that more-or-less comprehends the essentials of the longer list. One author, for example, reduced the number to fourteen essential items, and more recently Allport (1955) reduced them to six basic generalizations. The statements found in Gestalt theory are exemplified in the following:

1. Form is fundamental, and once it exists it tends to persist. There is parallelism or isomorphism between the form of underlying physiological

processes and perceptual experiences, although the experience of form need not be correlative with the external stimulus.

2. The form of a percept is not to be explained by some adding or combining of prior elements.

3. Field forces are the interacting influences that pervade the state of wholeness. A field can be considered as a system of interacting influences maintaining an equilibrium and thus maintaining a whole, or configuration. This field is viewed at both the physiological and the experiential levels.

4. The relation between the stimulus pattern received by the organism and the fields or wholes of perception may undergo transformation. An illustration of the retention of essential form while transformation is undergone is that a picture that has been drawn on a rubber sheet may retain its identity even when the sheet is later stretched out of its original shape. The literal characteristics of the picture do not remain as they were; nevertheless, it retains an essential resemblance to its original self.

Topological field theory

Topological psychology has seemed to have been an attempt to develop a consistent and exclusively phenomenological psychology, but viewed critically it has intermingled physicalistic and phenomenological terms and concepts. The phenomenological field is experienced as extending about the individual; the phenomenological experience of self and objects makes up the content of the field. The individual is treated as a point in space and can migrate from one portion of this life-space to another, thereby possessing a varying significance in the field. Perception has to do with the individual's comprehension of his positions.

Conclusions

It is not to be questioned that most of if not all these theories contain some truth. They assume properties that to some fair degree approximate the real nature of perception. They do in some cases, however, tend to overlap each other, and not all of them, in their present form, are necessary to complete a picture of perception.

THE SYMBOLIC NATURE OF PERCEIVING

The more one describes perception as obtaining information from the environment, or obtaining information about one's body state, through sensory mechanisms, the more one comes to realize that although *invariances* are a basis for the continuity and permanence of "perceived objects," there is an endless possibility in the perceiver for the construction of new relationships between himself and the environment. To hold strictly and

exclusively to the idea that the organism simply *resonates* to what exists in the energistic universe and does no constructing or contriving of anything is almost to believe that all the heavens and all the hells that various religions have postulated must literally exist because they have been believed in (that is, are resonances of externality). If the resonance idea covers the matter, man is just resonating to what exists.

The broad and endless possibility of the constructional nature of perception, although of sensory realities, allows when it is viewed from outside perception a kind of activity that is best described as a kind of symbolism, a development of "abstract" rather than "concrete" and direct relations between the perceiver and whatever it is that triggers off the perceiving.

Abstractness, the abstract nature of some reactions to stimulation, very often, if not always, involves symbolism. We therefore want to show how it is that one can speak of perception as symbolic. At first glance, symbolism may not seem an appropriate matter for solid science, but this belief, which may have held sway some years ago, is not nearly so common now. It can now be shown that symbolism is involved in perceptual response, and ways are being found to deal with it instead of excluding it from laboratory consideration.

There are two ways in which behavior may be called abstract. According to one, abstract behavior is perceptual behavior that depends for its differentiating characteristics upon some collateral contribution made by the higher brain centers that bring memory or conceptualization into play. Directly produced or "concrete" behavior, on the other hand, is behavior completely dominated by the stereotyped characteristics of the sensory pathways and peripheral mediating mechanisms. According to the second view of abstract behavior, behavior, regardless of what it is like, cannot be connected rigidly with some assignable characteristic of the stimulus.

In both views, abstractness has to do with something unusual and lacking in stereotopy. In the first, irregularity or unpredictability is provided by the central nervous system through its bringing concepts and memories into play. In the second, irregularity is introduced by having nothing in the stimulus to which one can point as being the crucial origin of the outcome. Let us examine some examples.

Let us take the case in which the observer perceives an apple to be *good*. That people can distinguish good apples from bad apples is not to be doubted. What, then, can be said about the cases in which this sort of perception occurs? Goodness is a quality that depends for its definition upon the perceiver's way of thinking. Goodness is a concept. Hence, when a person perceives an apple to be good, his perception is an application of his concept. Concepts of various perceivers differ. Therefore, the behavior of perceiving the apple to be good is an example of our first view of abstractness. It is an example because the perception is dependent upon a unique central nervous system contribution.

According to our second view of abstractness, the perception of goodness is not necessarily an example of behavioral abstractness. Abstractness is ruled out if, every time goodness is perceived, there is something about the stimulus that can be pointed to as the basis for goodness. If the good apple has no soft spots in it, then the stimulus is something different from when soft spots are detected. Goodness of the apple is a result of a certain kind of stimulus. The use to which this stimulus is put can vary quite greatly from person to person and can involve concepts and memories but, since there is a detectable stimulus basis, it is not abstract, according to the second way the term is used.

Symbols and signs

Let us be sure we know what is meant by a symbol and what symbolism is. The dictionary says, "A symbol is that which stands for or suggests something else by reason of relationship, association, or accidental but not intentional resemblance, especially a visible sign of something invisible, as an idea or quality." Thus, a symbol is a representative of something else. It stands for something which it in itself is not. The symbol substitutes by way of being or containing the essence of something while not copying the form. Sometimes a symbol is a part that stands for the whole. A symbol is something that carries vicarious meaning; the meaning is not inherent in the tangible item but arises only through the assignment or development of a functional relation of that item to something else. A symbol, being a specific thing, is a carrier of the meaning inherent in a class.

As far as the dictionary is concerned, the term symbol has a common synonym, *sign*. Thus we may tend to suppose that sign could be substituted for symbol. We find, however, that this is not the case. Several writers make a very definite and wholly justified distinction between the two words. The distinction is justified because there are two very different but related concepts to be labeled, and they thus require two words.

In the study of behavior, both animal and human, the word "sign" appropriately signifies the role that an impingement (the stimulus) plays. The stimulus is reacted to as a sign or an indication of something. This means that the impingement evokes a response of a specified kind. For example, a stimulus reacted to as a traffic light is reacted to as something that is a sign to stop or to proceed as the case may be. To put it another way, such a stimulus is reacted to as an indicator. When we call an impingement a stimulus, we simply imply that it is a source of *activation*. It is as if the organism acts by being prodded. Energistically, this is a part of the picture. But another way of looking at the matter is that certain impingements serve not exclusively as prods but as indicators, or provisions for determining what activity to perform, that is, what response to make.

It can be said, then, that both lower animals and men respond to stimuli as signs—that is, what the stimuli are to them. A word very similar

to sign is "signal." These two words may be synonymous. But, on the other hand, it could be said that a sign is that which signals. The sign is the agency, and the signaling is the process carried on by the agency.

How do signs and symbols differ? We have just said that impingements are signs by reason of the way they are reacted to by the person. What is a sign to one may not be to another. Or, what is one sign to one may be a different sign to another person or species, although the impingement is the same in all cases. A sign, however, does not stand for or substitute for something else, whereas a symbol does. We can say a target seen as a "traffic light" is a sign to go or to stop depending upon whether it is seen as a green light or red light. If it is a symbol, it is so only in a remote way. The light may symbolize the unpleasantness, for example, of one's last traffic arrest.

One author who has concerned himself with the matter of symbolism points out that people could not do some of the very commonest things, such as make-believe or lie, not to say plan for the future, if they were incapable of using symbols. Make-believe is a form of behavior that involves symbolism. It is a form of "acting as if." This sometimes seems to be impossible in certain asphasic individuals; such patients are able to respond to stimuli as signals but not as symbols. For instance, one patient was able to respond to the command "Drink it" when a glass of water was in front of him. He was unable to go through the make-believe (the symbolic behavior) of drinking when an empty glass was presented to him.

Symbolic response in animal behavior

We have been told, by certain animal experimenters, that subhuman beings do not manifest symbolic behavior; others state that they do. Surely the implied definitions of these two groups are not identical. Surely all agree on the descriptions of what animal subjects do. The difference must lie in the interpretation given.

Nissen (1951), for example, points out that what he calls symbolic behavior does occur. He says that symbolic behavior responding to stimuli that are not present at the time. This is true in the conditioned response. First, the animal responds to a given presentation. Along with this is juxtaposed another, which, by itself, may be ineffective. This second presentation (the to-be-conditioned impingement) either is not responded to at all or is responded to in a way very different from the first. After a number of repetitions, this second presentation evokes a response somewhat like the first. It is then that the animal is said to be responding to the stimulus that is not present; that is, it is behaving as if to the originally effective stimulus. It may be argued, however, that to state the matter in this form is highly figurative. What the animal is literally responding to is the stimulus that *is* present.

Reference to the earlier stimulus is made by the experimenter in his description of what the animal is doing now, as compared to what it did on the original occasion. Thus the experimenter, if he chooses to look at it that way, can envisage the present response as having symbolic relation to the stimulation that first evoked it but is now absent.

Perhaps, as far as the animal is concerned, the conditioned response cannot be used as a general example of symbolic behavior. It is response, at least, to a very literal event at the moment. How the impingement (the present stimulus) became effective need not be at issue, and thus reference to the original stimulus need not be made.

On the other hand, one whole segment of the study of animal and human behavior—namely, the study of learning—is given over to relating present behavior to past behaviors. Learning curves are drawn to show how behavior changes progressively from trial to trial. No single trial means anything by itself. If learning theory, then, can talk about present behavior in relation to past or future behavior, perhaps the theorist can rightfully talk about "responding to stimuli that are not present." We shall not be too decisive either one way or another about this point. Let it be something for us to think about further.

SUMMARY

The main effort in this final chapter was to reach the level of integration in description that would conform to the way the human organism actually interacts with the environment and thus maintain an organism-centered stance.

The chapter was not a description of perceptual behavior from a single theorist's standpoint but rather a rounding-up of the more comprehensive statements of several authors concerned with telling what perception is or how it functions. Notable among those who have written with this concern have been J. J. Gibson, Allport, and Helson. What these men have had to say has been summarized.

The various perceptual theories of a number of others have also been briefly characterized, with a caution that these are theories *about* perception but are not comprehensive theories *of* perception.

The chapter was written in the hope that by the time the reader had attended to the material regarding sense-modality functions, he would be able to properly utilize the insights of the men listed in this chapter to arrive at an effective view of perceptual response.

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